IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	BRUZZONE et al.	Examiner:	Ricky D. Shafer
Serial No.:	09/746,933	Group Art Unit:	2872
Filed:	December 22, 2000	Docket No.:	49837US051
Title:	REFLECTIVE LCD PROJECTION SYSTEM USING A WIDE-ANGLE POLARIZING BEAM SPLITTER		

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Date of Deposit: October 6, 2003
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By: Gwen M. Bruns
Gwen Bruns

Mail Stop Appeal Brief - Patents
Assistant Commissioner for Patents
Washington, D.C. 20231

- ☒ Appellant's Brief on Appeal in triplicate, including Appendices I -3
- ☒ Check(s) in the amount of $330.00 for filing Appeal Brief
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Customer Number 32692

Date: October 6, 2003

By: [signature]
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Reg. No. 40,337
IAM/gmb

OIPE JC109 OCT 0 6 2003 TRADEMARK OFFICE

Serial No. 09/746,933

PATENT

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By: ______________________
Name

APPELLANT'S BRIEF ON APPEAL

Mail Stop Appeal Brief – Patents
Assistant Commissioner for Patents
Washington, D.C. 20231

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Sir:

This Appeal Brief is presented in support of the Notice of Appeal submitted to the U.S. Patent and Trademark Office by facsimile on August 6, 2003, from the final rejection of claims 1, 2, 4-7 and 9-13 of the above-identified application, as set forth in the Office Action dated May 9, 2003.

A check for $320.00 to cover the required fee for filing this Brief is enclosed. An original and two copies of the Brief are enclosed herewith.

I. REAL PARTY OF INTEREST

The Real Party of Interest is 3M Innovative Properties Company, a Delaware corporation and a wholly owned subsidiary of 3M Company. 3M Innovative Properties Company is the assignee of the instant application.

II. RELATED APPEALS AND INTERFERENCES

There are no related appeals or interferences for the above-referenced patent application.

III. STATUS OF CLAIMS

Claims 1, 2, 4-7 and 9-13, as set forth in Appendix 1 attached herewith, are pending and are the subject of the present appeal.

The case was originally filed with claims 1-24. In an amendment dated November 27, 2001, claim 25 was added and minor corrections were made to claims 2, 3, 10 and 17. In a paper issued on February 27, 2002, (Appendix 2-A), Applicants were required to elect one of two species. In a response dated March 27, 2002 (Appendix 2-B), Applicants made preliminary amendments to the claims, canceling claims 20 and 21, and elected Species B, indicating that all pending claims read on the elected species. A restriction requirement and supplemental species election was issued on June 18, 2002 (Appendix 2-C). A response to the restriction requirement was submitted on July 18, 2002 (Appendix 2-D), in which Group I, claims 1-12 and 25, was elected with traverse. Also, the Appellants selected, with traverse, the following species: i) a rear projection system; ii) the first polarization direction being s-polarization and iii) the beamsplitter being a multilayer film beamsplitter. Appellants also indicated that claims 13 and 19 were generic.

An Office Action was issued on October 24, 2002 (Appendix 2-E). In the Office Action, the Examiner indicated that although claim 13 was considered to be generic, claim 19 was not considered to be generic. Claims 3, 8, 14-19 and 22-25 were withdrawn from consideration, and claims 1, 2, 4-7 and 9-13 were rejected. In a subsequent response (Appendix 2-F), mailed January 24, 2003, Appellants added new claim 26. In the Final Office Action dated May 9, 2003, (Appendix 2-G), claim 26 was

withdrawn from consideration. Consequently, claims 3, 8, 14-19 and 22-26 are currently withdrawn from consideration, and claims 1, 2, 4-7 and 9-13 are pending.

IV. STATUS OF AMENDMENTS

A response to the final Office Action dated May 9, 2003, was submitted by Appellants on July 9, 2003 (Appendix 2-H). Appellants presented arguments in this response to distinguish the claimed subject matter from the cited prior art, and requesting the Examiner to reconsider the claims.

By way of Advisory Action, mailed July 28, 2003, (Appendix 2-I), this Response was deemed not to place the application in condition for allowance, for the reasons set forth in the Final Office Action.

Since the response of May 9, 2003 included no amendments to the claims, there are no outstanding amendments. Therefore, the list of appealed claims presented in Appendix 1 lists the claims as finally rejected in the Office Action of May 9, 2003.

V. SUMMARY OF THE INVENTION

The invention is best described first with respect to claim 13. Claim 13 is directed to a projection system, for example such as is shown in FIGs. 1b and 2b below, and described generally at page 10, line 23 – page 14, line 23. The projection system includes a Cartesian polarizing beam splitter defining a first tilt axis and a color separation prism assembly that has a second tilt axis. The Cartesian polarizing beam splitter and the prism assembly are arranged such that the first and the second tilt axes are perpendicular to each other.

A definition of a Cartesian PBS is presented at page 7, lines 16-17, *viz.* a Cartesian PBS is one in which the polarization of the separate beams is referenced to invariant, generally orthogonal, principal axes of the PBS. A Cartesian PBS is further defined in the parent case (U.S. 6,485,997 B1), incorporated in the present application by reference, as having a structural orientation defining fixed polarization axes. A reflective Cartesian PBS substantially reflects those components of a beam of light

which are polarized along one such fixed axis, called the Material Axis (col. 4, lines 17-22).

Consequently, the interaction of the Cartesian PBS is characterized by how the incident light is polarized with respect to the PBS axis. For light in a polarization state that is transmitted by the PBS, a Cartesian PBS transmits substantially all the incident light, even if the incident light is not polarized parallel to the plane of incidence, so long as the light is polarized parallel to the correct axis of the polarizer. Examples of Cartesian polarizers include multiple polymer layer film polarizers and wire grid polarizers.

The tilt axis of the Cartesian PBS is shown in FIG. 2b as axis 56. The tilt axis lies in the plane of a reflecting/transmitting surface, and represents that axis about which the reflecting/transmitting surface is rotated, or tilted, so that the reflecting/transmitting surface is not normal to the incident light. Accordingly, light 60 enters the PBS 30 and is reflected by the PBS film 32 which is rotated about the tilt axis 56 so as to reflect the light at an angle of approximately 90°. The tilt axis is perpendicular to the plane of incidence, i.e. the plane formed by the directions of the incident light and the reflected light.

The light reflected from the PBS 30 is directed into the color prism assembly 36. The color prism assembly 36 has color separating surfaces that are non-normal to the incident light. The tilt axes of the color prism assembly are shown as axes 58. These tilt axes represent the axes about which the color separating surfaces would be rotated to make these surfaces normal to the incident light. In FIG. 2b, the tilt axes 58 of the prism assembly are perpendicular to the tilt axis 56 of the PBS 30. This contrasts with the system shown in FIG. 2a below, in which the tilt axes 58 of the prism assembly are parallel with the tilt axis of the PBS 30. In the invention of claim 13, the prism assembly has a tilt axis that is perpendicular to the tilt axis of the PBS, like the embodiment illustrated in FIG. 2b.

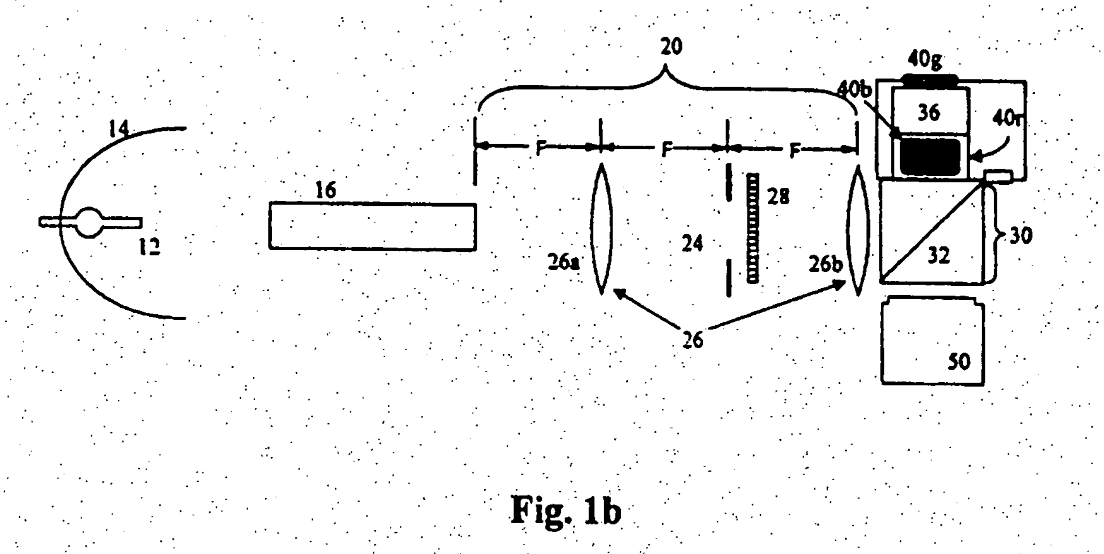

FIG. 1b from the present application

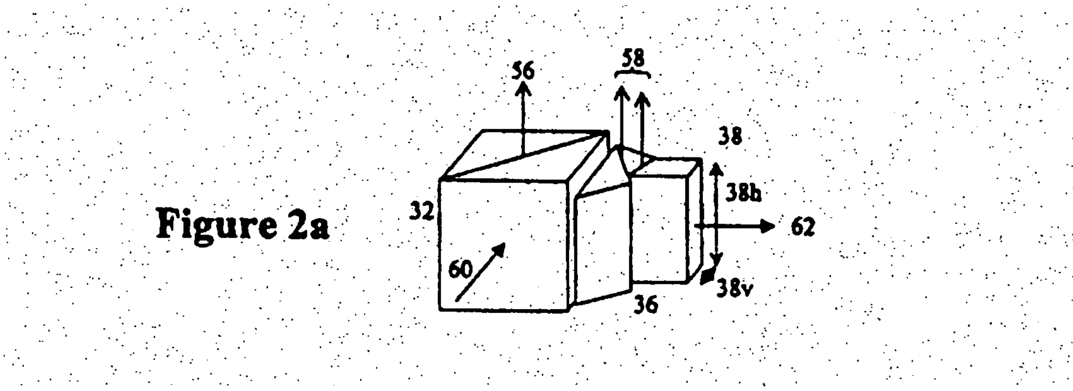

FIG. 2a from the present application

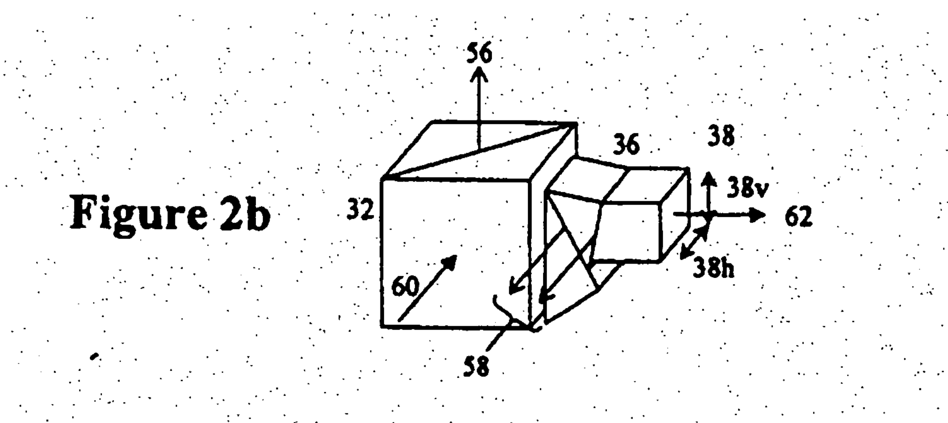

FIG. 2b from the present application

Since the tilt axis for an optical element lies perpendicular to the plane of incidence, i.e. the plane formed by the incoming and reflected light, a straightforward test for determining whether the tilt axis for the PBS is perpendicular to the tilt axis of the prism assembly is to examine the reflection planes for the PBS and the prism assembly. If the reflection planes of the PBS and prism assembly are perpendicular, then the tilt axes are perpendicular. If the reflection planes are parallel, then the tilt axes are parallel.

The invention of claim 1 is also described generally at page 10, line 23 – page 14, line 23, and with respect to FIGs. 1b and 2b. Claim 1 is directed to an optical imaging system that has an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5. A Cartesian polarizing beam-splitter has a first tilt axis and is oriented to receive the beam of light. The Cartesian polarizing beam splitter nominally polarizes the beam of light with respect to the Cartesian beam-splitter. A first polarized beam of light having a first polarization direction is folded by the Cartesian polarizing beam splitter and a second polarized beam of light having a second polarization direction is transmitted by the Cartesian polarizing beam splitter. This is shown in FIG. 1b, in which light from the light source 12 passes to the PBS 30. The PBS folds, by reflecting, light in the first polarization state and transmits light in the second polarization state.

A color separation and recombination prism 36 is optically aligned to receive one of the polarized beams of light. The prism has a second tilt axis, a plurality of color separating surfaces, and a plurality of exit surfaces. The second tilt axis is oriented perpendicularly to the first tilt axis of the Cartesian polarizing beam-splitter so that the polarized beam is nominally polarization rotated into the opposite polarization direction with respect to the color separating surfaces and a respective beam of colored light exits through each of the exit surfaces. In other words, if the PBS directs a beam of s-polarized light to the color prism, then that light is incident on the prism as p-polarized light because the tilt axis of the color prism is perpendicular to the tilt axis of the PBS.

There is a plurality of polarization modulating imagers, for example imagers 40b, 40g and 40r. Each imager is placed at one of the exit surfaces of the color separating

and recombining prism 36. Each imager receives one of the respective beams of colored light separated by the color separation and recombination prism. Each imager can separately modulate the polarization state of the respective incident beam of colored light.

VI. ISSUES PRESENTED FOR REVIEW

A. Whether claim 13 is rejected under 35 U.S.C. § 102(b) as being anticipated by Nagashima (JP 63039394).

B. Whether claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars (U.S. Patent No. 5,986,815) (Bryars '815).

C. Whether claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars et al. (U.S. Patent No. 6,144,498) (Bryars '498).

D. Whether claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Kuijper (U.S. Patent No. 6,250,762 B1).

E. Whether claim 13 is anticipated under 35 U.S.C. § 102(e) by Knox (U.S. Patent No. 6,390,626 B2).

F. Whether claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Nagashima in view of Duwaer et al. (U.S. Patent No. 5,146,248) (Duwaer).

G. Whether claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Bryars '815 in view of Duwaer.

H. Whether claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Bryars '498 in view of Duwaer.

I. Whether claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Kuijper in view of Duwaer.

J. Whether claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Knox in view of Duwaer.

VII. GROUPING OF CLAIMS

For consideration on this appeal, Appellant has grouped the Claims according to the grounds of rejection made in the final Office Action, as shown below:

Issue A:	Claim 13 only	
Issue B:	Claim 13 only	
Issue C:	Claim 13 only	
Issue D:	Claim 13 only	
Issue E:	Claim 13 only	
Issue F:	Group 1:	1, 2, 4-7 and 9-12
Issue G:	Group 1:	1, 2, 4-7 and 9-12
Issue H:	Group 1:	1, 2, 4-7 and 9-12
Issue I:	Group 1:	1, 2, 4-7 and 9-12
Issue J:	Group 1:	1, 2, 4-7 and 9-12

VIII. ARGUMENTS

Issue A: 102 Rejection of claim 1 based on Nagashima

Claim 13 is rejected under 35 U.S.C. §102 (b) as being anticipated by Nagashima (JP 63039394). Nagashima shows, in FIG. 1, a projection system having a polarizing beamsplitter (21) (PBS) that reflects light from a light source (23) towards a color prism assembly (11). FIG. 1 from Nagashima is shown below, along with FIG. 2b of the present application for comparison.

To anticipate a claim, the reference must teach every element of the claim. "A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." Verdegaal Bros. v. Union Oil Co. of California, 814 F.2d 628,631, 2 USPQ2d 1051 1053 (Fed. Cir.) 1987). "The identical invention must be shown in as complete detail as is contained in the...claim." Richardson v. Suzuki Motor Co., 868 F. 2d1226, 1236, 9 USPQ2d 1913, 1920 (Fed. Cir. 1989). Therefore, if a reference does not teach every element of the claim, then the reference does not anticipate the claim (MPEP § 2131).

Appellants' contend that Nagashima fails to teach all of the elements of claim 13 on at least two grounds, *viz.* i) the orientation of the tilt axes and ii) the lack of teaching a Cartesian polarizing beamsplitter. These are addressed in turn.

i) Orientation of the Tilt Axes

It is important to determine the direction of the tilt axes of the PBS and the color prism assembly in Nagashima's system. In order to illustrate the argument, FIG. 1 from Nagashims is shown below, along with FIG. 2b of the present application for comparison. As is stated above in the description of the invention provided above, the tilt axis lies in the plane of a reflecting/transmitting surface, and represents that axis about which the reflecting/transmitting surface is rotated, or tilted, so that the reflecting/transmitting surface is not normal to the incident light. For the PBS, the tilt axis lies in the plane of the polarized reflector and points out of the plane of the figure. As a result, the light is reflected in a plane parallel to the plane of the figure. Likewise, for the color prism assembly, the tilt axes lie out of the plane of the figure, with the result

that the color prism assembly reflects the light in a plane parallel to the plane of the figure. Consequently, the tilt axis of the Nagashima's PBS is parallel to the tilt axes of the color prism.

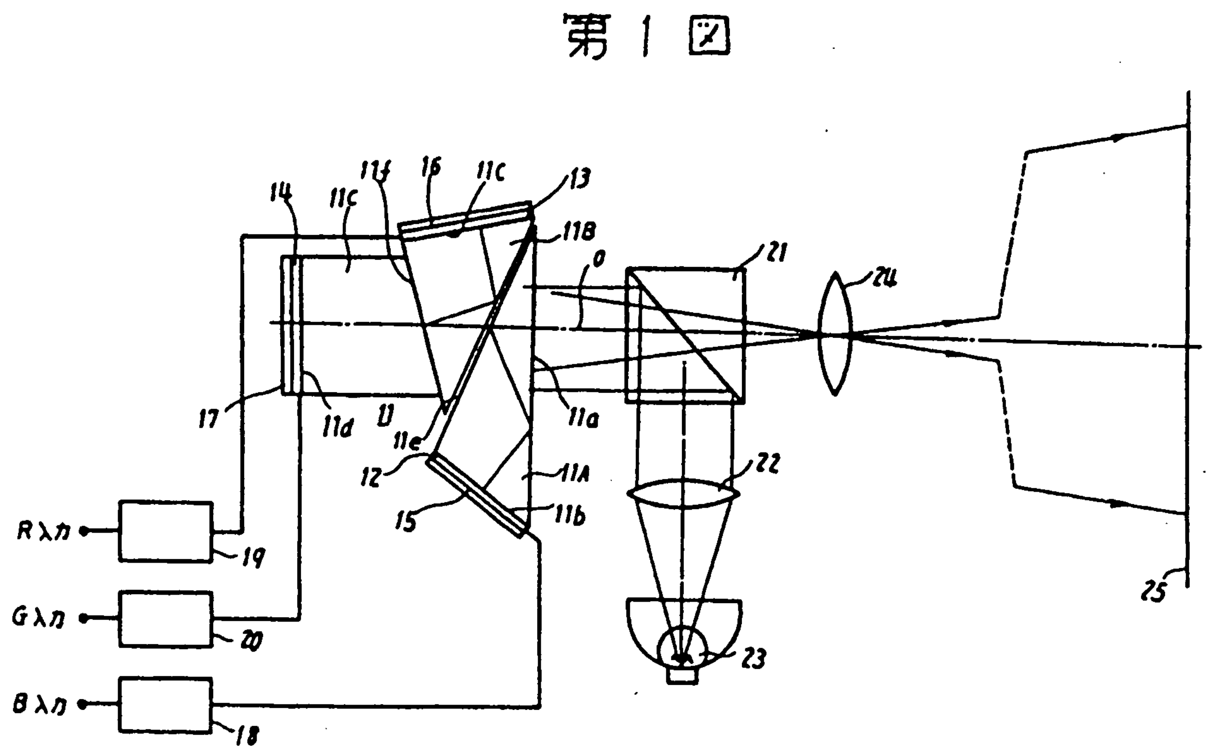

FIG. 1 of Nagashima

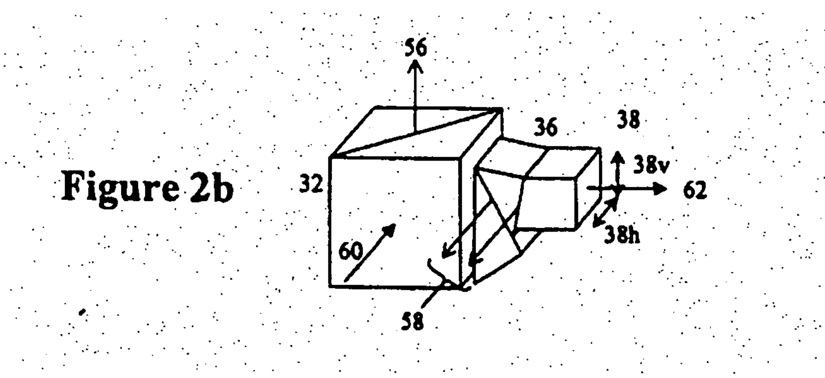

FIG. 2b of present Application.

Nagashima's system is different from the invention of claim 13, in which the tilt axes of the color prism and the PBS are perpendicular to one another.

Another way of viewing this is to determine where the planes of incidence lie for the PBS and for the color prism assembly. As is stated in the description of the invention provided above, where the plane of incidence for the prism assembly is perpendicular to that for the PBS, then the tilt axes are perpendicular. On the other hand, where the planes of incidence are parallel, then the tilt axes are parallel. Light reflected by Nagashima's PBS remains in the plane of the figure, and so the plane of incidence for Nagashima's PBS lies parallel to the plane of the figure. Likewise, the light reflected by Nagashima's color prism assembly remains in the plane of the figure, and so the plane of incidence for Nagashima's color prism assembly lies parallel to the plane of the figure. Accordingly, the tilt axes of the Nagashima's PBS and color prism assembly are parallel and are not perpendicular.

Thus, Nagashima fails to teach that the tilt axes of the PBS and color prism are perpendicular.

ii) Lack of Teaching of a Cartesian Polarizing Beamsplitter

Appellants also contend that Nagashima fails to teach the use of a Cartesian polarizing beamsplitter. As is stated above, a Cartesian polarizing beamsplitter is one in which the polarization of the separate beams is referenced to invariant, generally orthogonal, principal axes of the PBS, these axes being set by material properties of the PBS itself. For example, the principal axes of the PBS may be determined by the direction of wires in a wire grid polarizer or by the fast and slow axes of the birefringent layers in a multiplayer optical film polarizer. These principal axes arise due to the structure of the PBS, and are not defined simply by the function of the device.

Applicants respectfully contend that the Examiner is obliged to use the definition for the term "Cartesian polarizing beamsplitter" (Cartesian PBS) provided in the Specification: it is well known that the Applicant may be his own lexicographer so long as the meaning assigned to the term is not repugnant to the term's well known usage, *In re Hill* 161 F.2d 367, 73 USPQ 482 (CCPA 1947) (cited in MPEP § 2111.02).

Appellants contend that the phrase "Cartesian PBS" is not repugnant to its well known usage, if there is, in fact, well known usage of the term.

Accordingly, the term "Cartesian PBS" should be ascribed its meaning as presented in the Specification, i.e. it is a PBS in which the polarization of the beams is referenced to invariant principal axes of the PBS itself. Thus X-polarized light incident on the PBS is reflected as X-polarized light, irrespective of whether or not the polarization of the X-polarized light is perpendicular to the plane of incidence or not.

This contrasts with the performance of a conventional PBS, commonly referred to as a MacNeille PBS. In the MacNeille PBS, the light is separated into different polarization states primarily based on the effect that the reflection for p-polarization is zero when incident at Brewster's angle. Therefore, in a MacNeille polarizer, the polarization state of the incident light is characterized in terms of how the incident light is polarized with respect to the plane of incidence. As an example, incidence at Brewster's angle on a conventional polarizer surface results in light being totally transmitted, without reflection, only if the polarization of the light is parallel to the plane of incidence (p-polarized). If the light is incident on the surface in a direction not completely parallel to the plane of incidence, then there exists a reflected component. A MacNeille PBS works by presenting many surfaces for reflection: the overall effect of the many surfaces is that the reflectivity is low for p-polarized light and high for s-polarized light.

Thus, there is a significant difference between a Cartesian PBS and a MacNeille PBS. Nagashima fails to teach a Cartesian PBS.

In the Final Office Action, it is stated that the Examiner disagrees [with the contention that Nagashima fails to teach a Cartesian PBS] and is of the opinion that the PBS taught by Nagashima ...is inherently a Cartesian PBS due to the fact that the PBS splits incident light into first and second substantially polarized beams, wherein the polarization states thereof are inherently referenced to some co-ordinate system. Appellants respectfully contend that this description of a Cartesian PBS is in error. A Cartesian PBS does not simply produce first and second light beams whose polarization states are inherently referenced to <u>some co-ordinate system</u>. When a Cartesian PBS is used, the polarization states of the first and second beams are referenced to the

principal material axes of the PBS itself, and not to some arbitrary co-ordinate system. Nagashima simply fails to teach that the polarization states of the first and second beams are referenced to the principal material axes of the PBS itself. Instead, Nagashima refers to s-polarization and p-polarization, where the polarization states are referred to the plane of incidence and not to the principal material axes of the PBS itself.

Accordingly, Nagashima fails to disclose a Cartesian PBS.

Therefore, since Nagashima fails to teach all the elements of the claim, claim 13 is not anticipated by Nagashima.

Issue B: 102 Rejection of claim 13 based on Bryars '815

Claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars (U.S. Patent No. 5,986,815) (Bryars '815).

Bryars '815 teaches a projection system having a light source (10) that illuminates a PBS (20). The light reflected from the PBS is directed to a Philips type of prism assembly (30), formed by three prisms R, G, and B. Prism R has a reflecting surface (41b) and prism G has a reflecting surface (51b). The light red light entering the prism assembly from the PBS is reflected at surface (41b) and directed to the liquid crystal light valve (90). The remainder of the light, the green and blue portions, passes through surface (41b) to surface (51b), where the green light is reflected to the liquid crystal light valve (110) and the blue light is transmitted to the liquid crystal light valve (130).

Appellants contend that Bryars '815 also fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular, and the use of a Cartesian PBS.

<u>i) Tilt Axes</u>

Examination of the projection system taught by Bryars '815 (particularly FIG. 1, shown below along with FIG. 2b of the present application for comparison, and the description thereof at col. 10 line 1 - col. 12, line 41) shows that the tilt axes of the Bryars '815 system are parallel. Light is reflected from the light source in the plane of the figure, and so the tilt axis of the PBS lies perpendicularly out of the plane of the figure. Light is reflected within the prism assembly, at surfaces 41b and 51b, also within

the plane of the figure. Therefore, the tilt axes of the prism assembly also lie perpendicularly out of the plane of the figure. Accordingly, the tilt axes of the PBS and the color prism assembly are parallel, and so Bryars '815 fails to disclose that the tilt axes of the color prism assembly and the PBS are perpendicular.

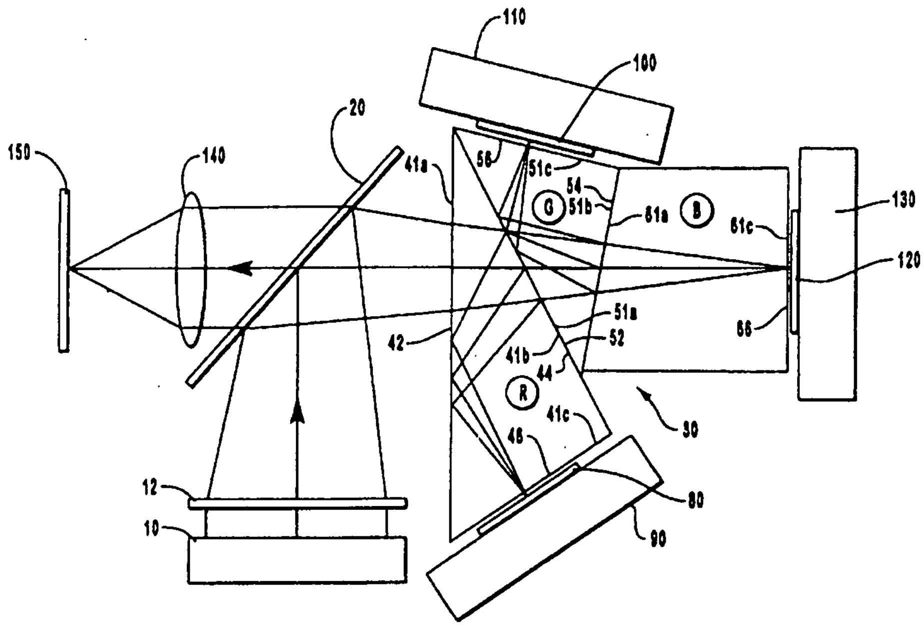

FIG. 1

FIG. 1 from Bryars '815

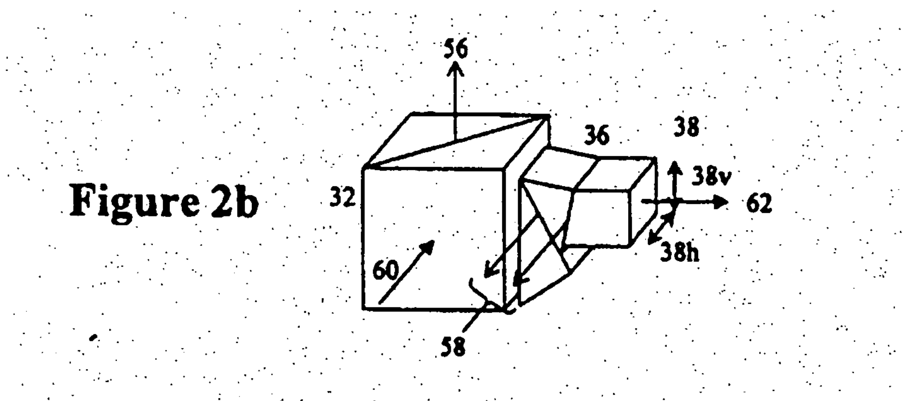

FIG. 2b from the present application

ii) Cartesian PBS

Like Nagashima, Bryars '815 fails to teach a PBS in which the polarization states of the first and second beams are referenced to principal material axes of the PBS itself. The Cartesian PBS has been described above with respect to the description fo the invention and Nagashima.

Instead, Bryars teaches (col. 10, lines 35-43) that the PBS transmits one type of polarization (either s- or p-polarized light, for the purpose of the example the transmitted light is p-polarized light) while reflecting light of the other type of polarization. S-polarized light refers to light which has its polarization vector perpendicular to the plane of incidence; whereas p-polarized light refers to light which has its polarization vector lying in the plane of incidence. Thus, Bryars '815 teaches the use of a conventional, MacNeille PBS, and not a Cartesian PBS.

Accordingly, Bryars '815 fails to teach all the elements of claim 13, and so claim 13 is not anticipated by Bryars '815.

Issue C: 102 Rejection of claim 13 based on Bryars '498

Claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars et al. (U.S. Patent No. 6,144,498) (Bryars '498). Bryars '498 teaches a projection system (100) having a light source (102) that illuminates a PBS (106). The light reflected from the PBS is directed to a Philips type of prism assembly (10), formed by three prisms R, G, and B. Prism R has a dichroic reflective coating on exit surface 22b and prism B has a dichroic reflective coating on exit surface 24b. The red light entering the prism assembly from the PBS is reflected at surface (22b) and directed to the red liquid crystal light valve (110). The remainder of the light, the green and blue portions, passes through surface (22b) to surface (24b), where the blue light is reflected to the blue liquid crystal light valve (111) and the green light is transmitted to the green liquid crystal light valve (114).

Appellants contend that Bryars '498 also fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular, and fails to teach the use of a Cartesian PBS.

i) Tilt Axes

Examination of the projection system taught by Bryars '498 (particularly FIG. 2, shown below along with FIG. 2b of the present application for comparison, and the description thereof at col. 4 line 59 - col. 6, line 8) shows that the tilt axes of the Bryars '498 system are parallel. Light is reflected from the light source in the plane of the figure, and so the tilt axis of the PBS lies perpendicularly out of the plane of the figure. Light is reflected within the prism assembly, at both surfaces 22b and 24b, also within the plane of the figure. Therefore, the tilt axes of the prism assembly also lie perpendicularly out of the plane of the figure. Since the tilt axes of the PBS and the color prism assembly lie out of the plane of the figure, the tilt axes are parallel and so Bryars '498 fails to disclose that the tilt axes of the color prism assembly and the PBS are perpendicular.

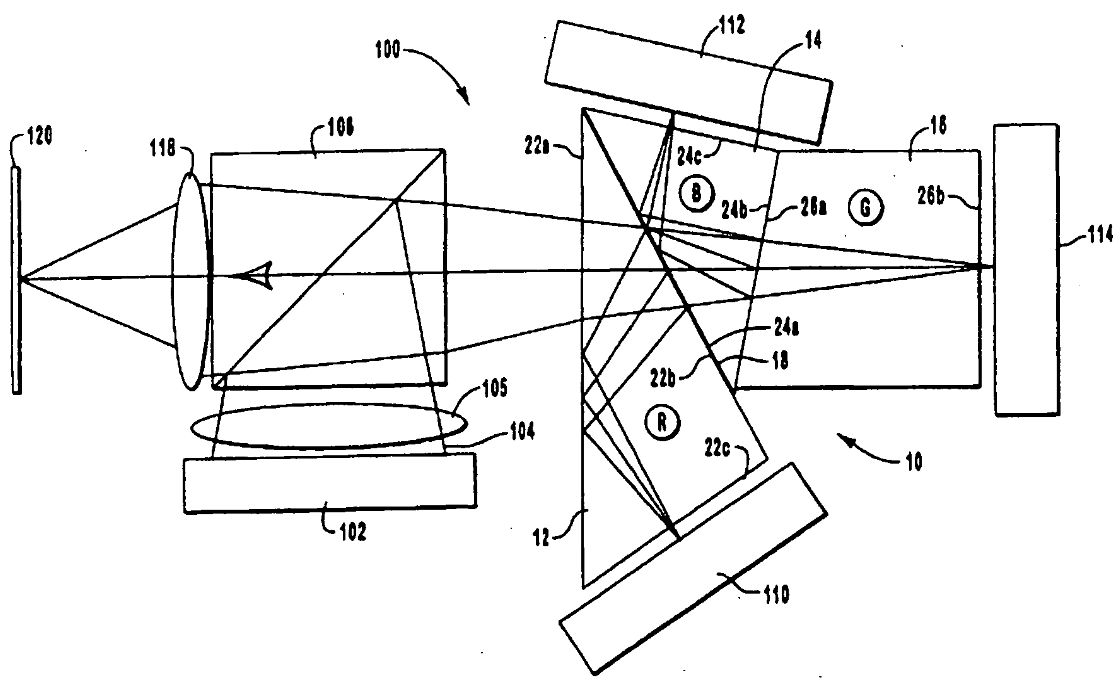

FIG. 2
(PRIOR ART)

FIG. 2 from Bryars '498

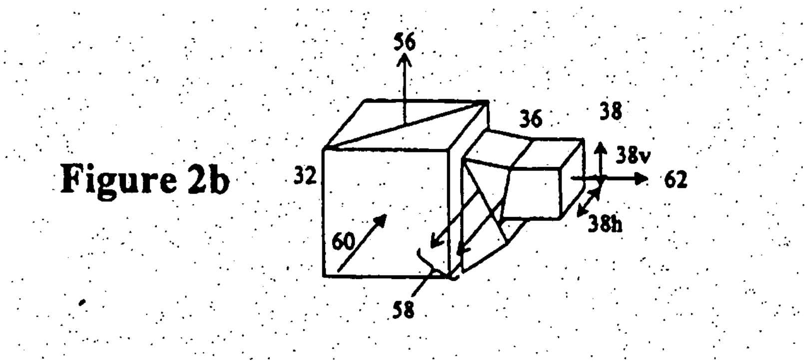

FIG. 2b from the present application

ii) Cartesian PBS

Like Nagashima, Bryars '498 fails to teach a PBS in which the polarization states of the first and second beams are referenced to principal material axes of the PBS itself. The Cartesian PBS has been described above with respect to the description of the invention and Nagashima.

Instead, Bryars '498 is silent as to the workings of the PBS. However, Bryars '498 does not teach that the PBS is of a type known to be a Cartesian PBS, nor that the PBS has principal material axes that define the polarization states of the reflected and transmitted light.

Accordingly, Bryars '498 fails to teach all the elements of claim 13, and so claim 13 is not anticipated by Bryars '498.

Issue D: 102 Rejection of claim 13 based on Kuijper

Claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Kuijper (U.S. Patent No. 6,250,762 B1). Kuijper teaches (FIGs. 1 and 3, and col. 2, line 62 – col. 3, line 36) a projection system having a light source (5) that illuminates a PBS (9). Light reflected by the PBS is directed to a color-separating element (17), comprised of three prisms 19, 21, and 23. Blue light is reflected at the first interface (25) between two of the prisms (19 and 23), and propagates to the light valve (15) for blue light. Red light is reflected at the second interface (27) between prisms (19 and 21) and propagates to the light valve (11) for red light. Green light passes through both

interfaces to the light valve (13) for green light. This arrangement of prisms is often referred to as a Philips prism.

Appellants contend that Kuijper also fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular, and fails to teach the use of a Cartesian PBS.

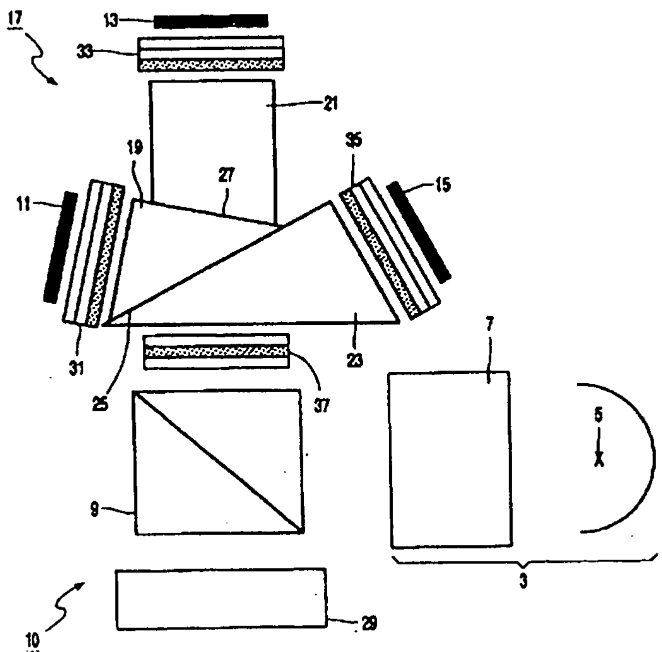

FIG. 1 from Kuijpers

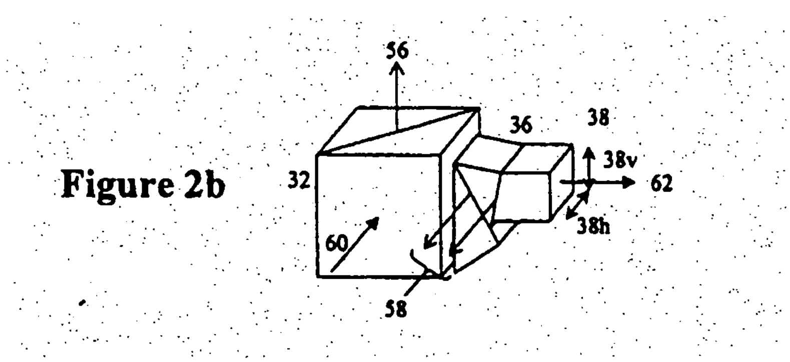

FIG. 2b from present application

i) Tilt Axes

Examination of the projection system taught by Kuijper (particularly FIG. 1, shown above along with FIG. 2b of the present application for comparison) shows that the tilt axes of Kuijper's system are parallel. Light is reflected from the light source in the plane of the figure and the tilt axis of the PBS lies perpendicularly out of the plane of the figure. Also, light is reflected within the prism assembly, at both interfaces (25 and 27), within the plane of the figure. The tilt axes of the prism assembly, therefore, also lie perpendicularly out of the plane of the figure. Accordingly, since the tilt axes of the PBS and the color prism assembly both lie out of the plane of the figure, the tilt axes of the PBS and the color prism assembly are parallel. Consequently, Kuijper fails to disclose that the tilt axes of the color prism assembly and the PBS are perpendicular.

ii) Cartesian PBS

Like Nagashima, Kuijper fails to teach a PBS in which the polarization states of the first and second beams are referenced to principal material axes of the PBS itself. The Cartesian PBS has been described above with respect to the description of the invention and Nagashima.

Instead, Kuijper is silent as to the workings of the PBS. However, Kuijper does not teach that the PBS is of a type known to be a Cartesian PBS, nor that the PBS has principal material axes that define the polarization states of the reflected and transmitted light.

Accordingly, Kuijper fails to teach all the elements of claim 13, and so claim 13 is not anticipated by Kuijper.

Issue E: 102 Rejection of claim 13 based on Knox

Claim 13 is anticipated under 35 U.S.C. § 102(e) by Knox (U.S. Patent No. 6,390,626 B2). Knox teaches a projection system having a light source (210) that illuminates a PBS (220). Light reflected by the PBS is directed to various embodiments of color separating prism assemblies, including an x-cube beamsplitter/combiner (230) in FIGs. 11, 12 and 12A, a Philips color prism (330), in FIGs. 13 and 17, a prism assembly (430) in FIG. 14, a prism (530) in FIG. 15, and a prism (630) in FIG. 16. FIGs.

13 and 14 are provided below, along with FIG. 2b from the present application for comparison. Each of the prism assemblies taught by Knox includes reflecting surfaces for separating and combining light of different colors. The light is directed from the prism assembly to two or three imagers, and is reflected to the prism assemblies where the light of different color is recombined. The recombined light then passes to the PBS and the image light that has been polarization rotated is passed to the projection lens (260).

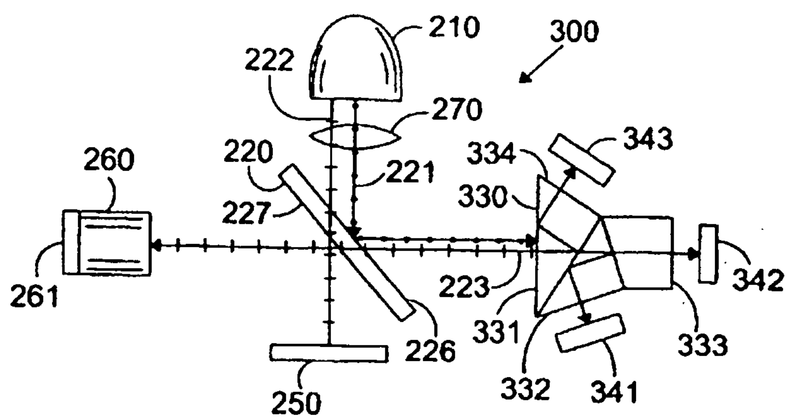

FIG. 13

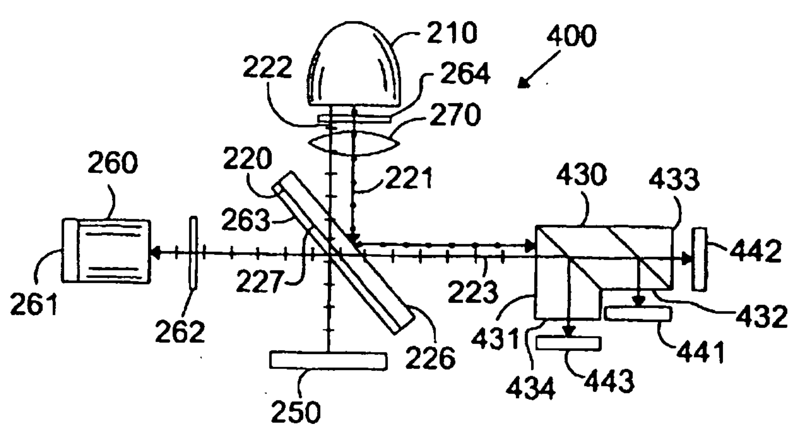

FIG. 14

FIGs. 13 and 14 from Knox

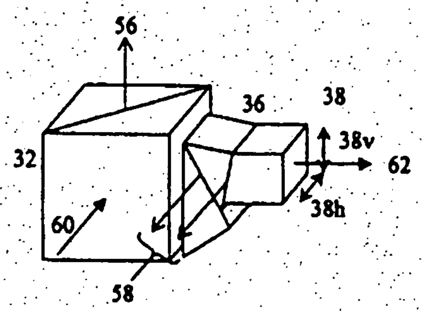

FIG. 2b from the present application.

The tilt axes of the PBS, however, and the reflecting surfaces in each prism assembly are all parallel. In each case, the plane of reflection for the PBS lies in the plane of the figure: therefore the tilt axis of the PBS in each case lies out of the plane of the figure. Also, the plane of reflection for each of the prism assemblies lies in the plane of the figure, and so the tilt axes of the prism assemblies lie out of the plane of the figure. Since the tilt axes of the PBS and the prism assemblies all lie out of the plane of the figure, the tilt axes are parallel. Moreover, there is no teaching in Knox that the prism assemblies could be rotated from the orientations shown in the figures to positions in which the tilt axes of the PBS and prism assemblies are perpendicular.

Therefore, Knox fails to teach that the tilt axes are perpendicular, and fails to teach all the elements of claim 13. Accordingly, claim 13 is not anticipated by Knox.

Issue F: 103 Rejection of claims 1, 2, 4-7 and 9-12 based on Nagashima and Duwaer

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Nagashima in view of Duwaer et al. (U.S. Patent No. 5,146,248) (Duwaer).

It is stated in the Final Office Action that Nagashima discloses all of the subject matter claimed, as described in the discussion of the rejection of claim 13, with the exception for explicitly stating that the illumination system has an f/# less than or equal to 2.5. It is further stated in the Office action that Duwaer teaches that it is well known to use an illumination system having an f/# less than or equal to 2.5 in the same field of

endeavor for the purpose of producing a large cone of light, and that it would have been obvious at the time the invention was made to modify the illumination system of Nagashima to include an illumination system having a f/# less than or equal to 2.5 as taught by Duwaer, in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

Duwaer discusses a light valve projection system based on the use of three separate light sources (30, 40 and 50) emitting light at different wavelengths (col. 6, line 59 – col. 7, line 2). Respective reflectors (34, 44, and 54) collect the light emitted by the light sources and direct the light through respective transmissive light valves (36, 46 and 56). The image light transmitted through the light valves is combined in a Philips color prism formed from three prisms (38, 48, 58), and is then projected using a projection lens (60). Duwaer indicates that the illumination system for this transmission-type imaging system may be as low as f/2.0 (col. 5, line 58 – col. 6, line 14) .

Three criteria must be met to establish a *prima facie* case of obviousness. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference. Second, there must be a reasonable expectation of success. Finally, the prior art reference, or combination of references, must teach or suggest all the claim limitations. MPEP § 2142. Appellants respectfully contend that the prior art fails to disclose all the claim limitations and there would be no motivation to combine the references as proposed by the Examiner.

In claim 1, like claim 13, the tilt axes of the PBS and color prism assembly are perpendicular. It was shown above that Nagashima fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular. Duwaer fails to correct this deficiency. In fact, Duwaer's system does not even include a PBS. Therefore, neither of the proposed references teach or suggest that the tilt axes of the PBS and the color prism assembly are perpendicular.

The optical imaging system of claim 1, like claim 13, includes a Cartesian PBS. It was shown above that Nagashima fails to teach or suggest the use of a Cartesian PBS. Duwaer also fails to rectify this deficiency, since Duwaer's projection system

does not use a PBS. Therefore, neither of the proposed references teach or suggest a Cartesian PBS.

Accordingly, the proposed combination of Nagashima and Duwaer fails to teach or suggest all the elements of claim 13.

Furthermore, Appellants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action. First, it is important to note that Duwaer teaches only the use of f/2.0 illumination for a system that is based on transmissive imagers. Duwaer does not teach or suggest that illumination units with such a low f/# are suitable for use with reflective imagers: projection systems that use transmissive imagers typically do not use a PBS. Therefore, for one of ordinary skill in the art to have any reasonable expectation of success in combining Duwaer's light source with Nagashima's system, the one of ordinary skill would be required to know that a PBS capable of maintaining an acceptable level of contrast with such a low f/# was available. There is no teaching in Nagashima, however, that would lead of ordinary skill in the art to believe that image contrast would be maintained when using a light source with such a wide angle of illumination.

The problems associated with using a conventional polarizer in a projection system having an f/# of 2.5 or less were known and are discussed at length in the parent application (U.S. 09/312,917), which is incorporated by reference in the present application. Appellants respectfully suggest that, since the solution to achieving a truly a wide angle polarizer was not known to one of ordinary skill, it would not be reasonable for one of ordinary skill to combine an illumination system, as taught by Duwaer, into Nagashima's system.

Accordingly, two of the three criteria for a *prima facie* case for obviousness have not been met, *viz.* that all the claim elements be taught in the proposed combination of references and that one of ordinary skill would have a reasonable expectation of success in making the combination. Consequently, claim 1 is not unpatentable over the proposed combination of references, and so claim 1 is allowable.

While Appellants have selected claim 1 to represent Group 1 in this Issue, Appellants do not admit that claims 2, 4-7 and 9-12 are not separately patentable over the proposed combination of Nagashima and Duwaer.

Issue G: 103 Rejection of claims 1, 2, 4-7 and 9-12 based on Bryars '815 and Duwaer

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Bryars '815 in view of Duwaer, both of which have been described above. It was shown above that Bryars '815 fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular. Duwaer fails to correct this deficiency: Duwaer's system does not include a PBS and Duwaer does not refer to the use of a PBS. Therefore, neither of the proposed references teach or suggest, either individually or in combination, that the tilt axes of the PBS and the color prism assembly are perpendicular.

The optical imaging system of claim 1, like claim 13, includes a Cartesian PBS. It was shown above that Bryars '815 fails to teach or suggest the use of a Cartesian PBS. Duwaer also fails to rectify this deficiency, since Duwaer does not refer to a PBS. Therefore, neither of the proposed references, individually or in combination, teach or suggest a Cartesian PBS. Accordingly, the proposed combination of Bryars '815 and Duwaer fails to teach or suggest all the elements of claim 1.

Furthermore, Appellants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action, for reasons similar to those described above with respect to the proposed combination of Nagashima and Duwaer.

Two of the three requirements for a *prima facie* case of obviousness have not been met, *viz.* that all the claim elements be taught in the proposed combination of Bryars '815 and Duwaer, and that one of ordinary skill would have a reasonable expectation of success in making the combination. Consequently, claim 1 is not unpatentable over the proposed combination of Bryars '815 and Duwaer, and so claim 1 is allowable.

While Appellants have selected claim 1 to represent Group 1 in this Issue, Appellants do not admit that claims 2, 4-7 and 9-12 are not separately patentable over the proposed combination of Bryars '815 and Duwaer.

Issue H: 103 Rejection of claims 1, 2, 4-7 and 9-12 based on Bryars '498 and Duwaer

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Bryars '498 in view of Duwaer, both of which have been described above. It was shown above that Bryars '498 fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular. Duwaer fails to correct this deficiency: Duwaer's system does not include a PBS. Therefore, neither Bryars '498 nor Duwaer teach or suggest, either individually or in combination, that the tilt axes of the PBS and the color prism assembly are perpendicular.

The optical imaging system of claim 1, like claim 13, includes a Cartesian PBS. It was shown above that Bryars '498 fails to teach or suggest the use of a Cartesian PBS. Duwaer also fails to rectify this deficiency, since Duwaer does not refer to a PBS. Therefore, neither of the proposed references, individually or in combination, teach or suggest a Cartesian PBS. Accordingly, the proposed combination of Bryars '498 and Duwaer fails to teach or suggest all the elements of claim 1.

Furthermore, Appellants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action, for reasons similar to those described above with respect to the proposed combination of Nagashima and Duwaer.

The *prima facie* case of obviousness has failed because the proposed combination of Bryars '498 and Duwaer fails to teach or suggest all the elements and because one of ordinary skill would have no reasonable expectation of success in making the combination. Consequently, claim 1 is not unpatentable over the proposed combination of Bryars '498 and Duwaer, and so claim 1 is allowable.

While Appellants have selected claim 1 to represent Group 1 in this Issue, Appellants do not admit that claims 2, 4-7 and 9-12 are not separately patentable over the proposed combination of Bryars '498 and Duwaer.

Issue I: 103 Rejection of claims 1, 2, 4-7 and 9-12 based on Kuijper and Duwaer

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Kuijper in view of Duwaer, both of which have been described above. It was shown above that Kuijper fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular. Duwaer fails to correct this deficiency: Duwaer's system does not even include a PBS. Therefore, neither Kuijper nor Duwaer teach or suggest, either individually or in combination, that the tilt axes of the PBS and the color prism assembly are perpendicular.

The optical imaging system of claim 1, like claim 13, includes a Cartesian PBS. It was shown above that Kuijper fails to teach or suggest the use of a Cartesian PBS. Duwaer also fails to rectify this deficiency, since Duwaer does not refer to a PBS. Therefore, neither of the proposed references, individually or in combination, teach or suggest a Cartesian PBS. Accordingly, the proposed combination of Kuijper and Duwaer fails to teach or suggest all the elements of claim 13.

Furthermore, Appellants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action, for reasons similar to those described above with respect to the proposed combination of Nagashima and Duwaer.

The criteria for the *prima facie* case of obviousness have not been met. In particular, the proposed combination of refernefces fails to teach or suggest all the elements of claim 1 and one of ordinary skill would have no reasonable expectation of success in making the combination. Consequently, claim 1 is not unpatentable over the proposed combination of Kuijper and Duwaer, and so claim 1 is allowable.

While Appellants have selected claim 1 to represent Group 1 in this Issue, Appellants do not admit that claims 2, 4-7 and 9-12 are not separately patentable over the proposed combination of Kuijper and Duwaer.

Issue J: 103 Rejection of claims 1, 2, 4-7 and 9-12 based on Knox and Duwaer

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Knox in view of Duwaer, both of which have been described above.

It was shown above that Knox fails to teach that the tilt axes of the PBS and the color prism assembly are perpendicular. Duwaer fails to correct this deficiency: Duwaer's system does not include a PBS. Therefore, neither Knox nor Duwaer teach or suggest, either individually or in combination, that the tilt axes of the PBS and the color prism assembly are perpendicular.

Furthermore, Appellants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action, for reasons similar to those described above with respect to the proposed combination of Nagashima and Duwaer.

The criteria for the *prima facie* case of obviousness have not been met. In particular, the proposed combination of references fails to teach or suggest all the elements of claim 1 and one of ordinary skill would have no reasonable expectation of success in making the combination. Consequently, claim 1 is not unpatentable over the proposed combination of Knox and Duwaer, and so claim 1 is allowable.

CONCLUSION

Appellants respectfully submit that claim 13 is not anticipated by the cited art and that no *prima facie* showing of obviousness has been established with respect to claims 1, 2, 4-7 and 9-12, the rejections of which are contested by Appellants. It is earnestly requested that the rejections be reversed, and that all of the pending claims 1, 2, 4-7 and 9-13 be allowed.

If a telephone conference would be helpful in resolving any issues concerning this communication, please contact Iain A. McIntyre at 612-436 9610.

Respectfully submitted,

Customer No. 32692

Date: October 6, 2003

By: [signature]

Iain A. McIntyre
Reg. No. 40,337
Direct Dial: 612.436.9610

APPENDIX 1

THE CLAIMS ON APPEAL

1. An optical imaging system comprising:
   a) an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5;
   b) a Cartesian polarizing beam-splitter having a first tilt axis, oriented to receive the beam of light, wherein the Cartesian polarizing beam splitter nominally polarizes the beam of light with respect to the Cartesian beam-splitter, wherein a first polarized beam of light having a first polarization direction is folded by the Cartesian polarizing beam splitter and a second polarized beam of light having a second polarization direction is transmitted by the Cartesian polarizing beam splitter;
   c) a color separation and recombination prism optically aligned to receive one of the polarized beams of light, said prism having a second tilt axis, a plurality of color separating surfaces, and a plurality of exit surfaces, wherein the second tilt axis is oriented perpendicularly to the first tilt axis of the Cartesian polarizing beam-splitter so that the polarized beam is nominally polarization rotated into the opposite polarization direction with respect to the color separating surfaces and a respective beam of colored light exits through each of the exit surfaces; and
   d) a plurality of polarization modulating imagers, each imager placed at one of the exit surface of the color separating and recombining prism to receive one of the respective beams of colored light, wherein each imager can separately modulate the polarization state of the beam of colored light incident on said imagers.

2. The optical imaging system of claim 1, wherein the first polarization direction is nominally s-polarization and the second polarization direction is nominally p-polarization.

4. The optical imaging system of claim 1, wherein the illumination system provides a beam of substantially pre-polarized light.

5. The optical imaging system of claim 1, wherein the color separation and recombination prism includes at least three exit surfaces, and the plurality of imagers includes at least three imagers, wherein each of the colored light beams is a different color and each imager receives one of the different color light beams.

6. The optical imaging system of claim 1, wherein each imager reflects a polarization modulated image, wherein the images reflected by the imagers enter the color separation and recombination prism and the prism recombines the images into a single combined image, wherein the combined image is transmitted by the Cartesian polarizing beam splitter.

7. The optical imaging system of claim 6, further comprising a projection lens assembly, wherein the combined image is projected by the lens assembly onto a surface for viewing.

9. The optical imaging system of claim 1, wherein the optical system is a rear projection system.

10. The optical imaging system of claim 1, wherein the color separation and recombination prism includes a Philips prism.

11. The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter includes a multilayer optical film.

12. The optical imaging system of claim 1, wherein the polarization modulating imagers include a LCOS imager.

13. A projection system comprising:

a) a Cartesian polarizing beam splitter, the Cartesian polarizing beam splitter defining a first tilt axis;

b) a color separation prism assembly, the prism assembly having a second tilt axis;

c) wherein the Cartesian polarizing beam splitter and the prism assembly are arranged such that the first and the second tilt axes are perpendicular to each other.

APPENDIX 2

OFFICE ACTIONS AND AMENDMENTS/RESPONSES

A. First Requirement to Elect Species, February 27, 2002

B. Election of Species, March 27, 2002

C. Restriction Requirement and Election of Species, June 18, 2002

D. Response to Restriction Requirement, July 18, 2002

E. First Office Action, October 24, 2002

F. Response to First Office Action, January 24, 2003

G. Final Office Action, May 9, 2003

H. Response to Final Office Action, July 9, 2003

I. Advisory Action, July 28, 2003

APPENDIX 3

REFERENCES RELIED UPON BY THE EXAMINER

A. JP Patent Publication 63039394 (Nagashima).

B. U.S. Patent No. 5,986,815 (Bryars '815).

C. U.S. Patent No. 6,144,498 (Bryars '498).

D. U.S. Patent No. 6,250,762 B1 (Kuijper).

E. U.S. Patent No. 6,390,626 B2 (Knox).

APPENDIX 2

OFFICE ACTIONS AND AMENDMENTS/RESPONSES

A. First Requirement to Elect Species, February 27, 2002

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H. Response to Final Office Action, July 9, 2003

I. Advisory Action, July 28, 2003

APPENDIX 2

A. First Requirement to Elect Species, February 27, 2002

VUB

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/746,933	12/22/2000	Charles L. Bruzzone	~~55376USA4A~~ 051 49837US051	3760

7590 02/27/2002

OFFICE OF INTELLECTUAL PROPERTY COUNSEL
3M INNOVATIVE PROPERTIES COMPANY

MAR 4 2002

REFERRED TO

Office of Intellectual Property Counsel
3M Innovative Properties Company
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St. Paul, MN 55133-3427

EXAMINER	
SHAFER, RICKY D	
ART UNIT	**PAPER NUMBER**
2872	

DATE MAILED: 02/27/2002

1 month RR 27 Mar 02
6 month RR 27 Aug 02

Please find below and/or attached an Office communication concerning this application or proceeding.

03/27/02
YTF
sra

Yen Florczak

MAR 07 2002 ✓ yf 3/7/02

PTO-90C (Rev. 07-01)

Office Action Summary

Application No.	Applicant(s)	
09/746,933	BRUZZONE ET AL	
Examiner	Group Art Unit	
RD SHATER	2872	

—The MAILING DATE of this communication appears on the cover sheet beneath the correspondence address—

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 1 month MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, such period shall, by default, expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

☒ Responsive to communication(s) filed on 1/17/02.

☐ This action is **FINAL.**

☐ Since this application is in condition for allowance except for formal matters, **prosecution as to the merits is closed** in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 1 1; 453 O.G. 213.

Disposition of Claims

☒ Claim(s) 1-25 is/are pending in the application.

Of the above claim(s) ____ is/are withdrawn from consideration.

☐ Claim(s) ____ is/are allowed.

☐ Claim(s) ____ is/are rejected.

☐ Claim(s) ____ is/are objected to.

☒ Claim(s) 1-25 are subject to restriction or election requirement

Application Papers

☐ The proposed drawing correction, filed on ____ is ☐ approved ☐ disapproved.

☐ The drawing(s) filed on ____ is/are objected to by the Examiner

☐ The specification is objected to by the Examiner.

☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119 (a)-(d)

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119 (a)-(d).

☐ All ☐ Some* ☐ None of the:

☐ Certified copies of the priority documents have been received.

☐ Certified copies of the priority documents have been received in Application No. ____.

☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a))

*Certified copies not received: ____.

Attachment(s)

☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). ____

☐ Notice of Reference(s) Cited, PTO-892

☐ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Interview Summary, PTO-413

☐ Notice of Informal Patent Application, PTO-152

☐ Other ____

Office Action Summary

1. This application contains claims directed to the following patentably distinct species of the claimed invention:

A). The species depicted by Fig. 1a; and

B). The species depicted by Fig. 1b.

Applicant is required under 35 U.S.C. 121 to elect a single disclosed species for prosecution on the merits to which the claims shall be restricted if no generic claim is finally held to be allowable. Currently, claim 19 is generic.

Applicant is advised that a reply to this requirement must include an identification of the species that is elected consonant with this requirement, and a listing of all claims readable thereon, including any claims subsequently added. An argument that a claim is allowable or that all claims are generic is considered nonresponsive unless accompanied by an election.

Upon the allowance of a generic claim, applicant will be entitled to consideration of claims to additional species which are written in dependent form or otherwise include all the limitations of an allowed generic claim as provided by 37 CFR 1.141. If claims are added after the election, applicant must indicate which are readable upon the elected species. MPEP § 809.02(a).

Should applicant traverse on the ground that the species are not patentably distinct, applicant should submit evidence or identify such evidence now of record showing the species to be obvious variants or clearly admit on the record that this is the case. In either instance, if the examiner finds one of the inventions unpatentable over the prior art, the evidence or admission may be used in a rejection under 35 U.S.C. 103(a) of the other invention.

2. Applicant is advised that the reply to this requirement to be complete must include an election of the invention to be examined even though the requirement be traversed (37 CFR 1.143).

3. Applicant is reminded that upon the cancellation of claims to a non-elected invention, the inventorship must be amended in compliance with 37 CFR 1.48(b) if one or more of the currently named inventors is no longer an inventor of at least one claim remaining in the application. Any amendment of inventorship must be accompanied by a petition under 37 CFR 1.48(b) and by the fee required under 37 CFR 1.17(I).

4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to R.D. Shafer whose telephone number is (703) 308-4813.

RDS

February 25, 2002

2872

B. Election of Species, March 27, 2002

S/N 09/746,933 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Bruzzone et al.	Examiner:	Shafer, Ricky D.
Serial No.:	09/746,933	Group Art Unit:	2872
Filed:	12/22/00	Docket No.:	49837US051
Title:	REFLECTIVE LCD PROJECTION SYSTEM USING A WIDE-ANGLE POLARIZING BEAM SPLITTER		

I hereby certify that this paper is being transmitted by facsimile to the U.S. Patent and Trademark Office on the date shown below.

Virginia Bergstrom
Virginia Bergstrom

March 27, 2002
Date

PRELIMINARY AMENDMENT AND RESPONSE TO SPECIES ELECTION REQUIREMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

IN THE CLAIMS

Kindly cancel claims 20 and 21 without prejudice or disclaimer.

Kindly amend claims 19 and 24 to read as follows:

19. (Amended) A projection engine for displaying an image, the projection engine comprising:

a) a Cartesian polarizing beam-splitter having invariant, generally orthogonal principal axes including a first tilt axis; wherein the Cartesian polarizing beam splitter reflects a first polarization component beam of an incident beam of light and transmits a second polarization component beam, the

polarization of the separate component beams being referenced to the principal axes; and

b) a color separating prism assembly, optically aligned to receive one of the polarization component beams, the prism assembly having a plurality of color separating surfaces having tilt axes, the tilt axes of the color separating surfaces being perpendicular to the first tilt axis of the Cartesian polarizing beam splitter.

24. (Amended) The projection engine of claim 23,

a) further comprising a projection lens assembly;

b) wherein each imager is a polarization modulating reflective imager and the prism assembly is a color separating and recombining prism assembly;

c) wherein the prism assembly receives the one polarization component beam and separates the polarization component beam into a plurality of color beams;

d) wherein each color beam exits through a respective exit surface and a portion of the color beam is polarization modulated and reflected by the respective imager; and

e) wherein the reflected portions of the color beams re-enter the prism assembly and are recombined into a single image beam, the image beam being directed by the Cartesian polarizing beam splitter to the projection lens assembly, wherein the projection lens assembly projects an image.

REMARKS

Claims 1-19 and 22-~~24~~ 25 are pending in the application. Claims 19 and 24 have been amended. Claim 19 has been rewritten to include features from claim 21. Claim 24 has been rewritten to correct grammatical and spelling errors. Claims 20 and 21 have been canceled without prejudice or disclaimer.

In response to the species election requirement dated February 27, 2001, Applicants hereby elect species B, depicted *inter alia* by FIGs. 1b and 2b. All pending claims read on the elected species.

Any questions regarding this communication should be directed to the undersigned attorney at 952-253-4110.

Respectfully submitted,

Altera Law Group, LLC
6500 City West Parkway, Suite 100
Minneapolis, MN 55344
(952)-253-4110

Date: March 27, 2002 By: Iain A. McIntyre

Iain A. McIntyre
Reg. No. 40,337
IAM/vlb

Appendix A

Marked Up Copy of Amended Claims

Kindly cancel claims 20 and 21 without prejudice or disclaimer.

Kindly amend claims 19 and 24 as follows:

19. (Amended) A projection engine for displaying an image, the projection engine comprising:

a) a Cartesian polarizing beam-splitter having invariant, generally orthogonal principal axes including a first tilt axis; wherein the Cartesian polarizing beam splitter reflects a first polarization component beam of an incident beam of light and transmits a second polarization component beam, the polarization of the separate component beams being referenced to the principal axes; and

b) a color separating prism assembly, optically aligned to receive one of the polarization component beams, the prism assembly having a plurality of color separating surfaces having tilt axes, the tilt axes of the color separating surfaces being perpendicular to the first tilt axis of the Cartesian polarizing beam splitter.

24. (Amended) The projection engine of claim 23,

a) further comprising a projection lens assembly;

b) wherein each imager is a polarization modulating reflective imager and the prism assembly is a color separating and [recombinating] recombining prism assembly;

c) wherein the prism assembly receives the one polarization component beam and separates the polarization component beam into a plurality of color beams;

d) wherein each color beam exits through a respective exit surface and a portion of the color beam is polarization modulated and reflected by the respective imager; and

e) wherein the reflected portions of the color beams [reenters] re-enter the prism assembly and are recombined into a single image beam, the image beam being directed by the Cartesian polarizing beam splitter to the projection lens assembly, wherein the projection lens assembly projects an image.

C. Restriction Requirement and Election of Species, June 18, 2003

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/746,933	12/22/2000	Charles L. Bruzzone	~~55376USA4A~~ 49837US051	3760

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7590 06/18/2002

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OFFICE OF INTELLECTUAL PROPERTY COUNSEL
3M INNOVATIVE PROPERTIES COMPANY
JUN 24 2002

EXAMINER	
SHAFER, RICKY D	
ART UNIT	PAPER NUMBER
2872	

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DUE DATE (S) 7/18/02
ATTORNEY YTF
DOCKETED BY
REFERRED TO

Please find below and/or attached an Office communication concerning this application or proceeding.

1 Month Rest Req. 18 JUL 02
6 month RR 18 DEC 02

Yen Florczak

Yen Florczak

PTO-90C (Rev. 07-01)

Office Action Summary	Application No. 09/746,933	Applicant(s) BRUZZONE ET AL
	Examiner R.D. SHAFER	Group Art Unit 2872

—The MAILING DATE of this communication appears on the cover sheet beneath the correspondence address—

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 1 MONTH MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, such period shall, by default, expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

☒ Responsive to communication(s) filed on 3/27/02

☐ This action is **FINAL.**

☐ Since this application is in condition for allowance except for formal matters, **prosecution as to the merits is closed** in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 1 1; 453 O.G. 213.

Disposition of Claims

☒ Claim(s) 1-19 AND 22-25 is/are pending in the application.

Of the above claim(s) ______ is/are withdrawn from consideration.

☐ Claim(s) ______ is/are allowed.

☐ Claim(s) ______ is/are rejected.

☐ Claim(s) ______ is/are objected to.

☒ Claim(s) 1-19 AND 22-25 are subject to restriction or election requirement

Application Papers

☐ The proposed drawing correction, filed on ______ is ☐ approved ☐ disapproved.

☐ The drawing(s) filed on ______ is/are objected to by the Examiner

☐ The specification is objected to by the Examiner.

☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119 (a)-(d)

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119 (a)-(d).

☐ All ☐ Some* ☐ None of the:

☐ Certified copies of the priority documents have been received.

☐ Certified copies of the priority documents have been received in Application No. ______.

☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a))

*Certified copies not received: ______.

Attachment(s)

☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). ______

☐ Notice of Reference(s) Cited, PTO-892

☐ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Interview Summary, PTO-413

☐ Notice of Informal Patent Application, PTO-152

☐ Other ______

Office Action Summary

1. Applicant's election of Species "B", depicted by Fig. 1b, in Paper No. 12 is acknowledged.

2. Restriction to one of the following inventions is required under 35 U.S.C. 121:

   I. Claims 1-12 and 25, drawn to an optical imaging system comprising an illumination system having a f/# less than or equal to 2.5, a Cartesian polarizing beam splitter, a color separation and recombination prism and a plurality of polarization modulating imagers, classified in class 359, subclass 256.

   II. Claim 14, drawn to a projection system comprising an illumination system having a f/# less than or equal to 2.5, a Cartesian polarizing beam splitter and a color separation prism assembly, classified in class 359, subclass 495.

   III. Claims 15 and 16, drawn to a projection system comprising a Cartesian polarizing beam splitter and a color separation prism assembly, wherein the projection system is a front or rear projection system, classified in class 359, subclass 495.

   IV. Claims 17, drawn to a projection system comprising a Cartesian polarizing beam splitter and a color separation prism assembly with particular color separation prism details, classified in class 359, subclass 495.

   V. Claim 18, drawn to a projection system comprising a Cartesian polarizing beam splitter and a color separation prism assembly with particular polarizing beam splitter details, classified in class 359, subclass 498.

VI. Claim 22, drawn to a projection system comprising an illumination system having a f/# less than or equal to 2.5, a Cartesian polarizing beam splitter and a color separation prism assembly having a plurality of color separating surfaces with tilt axes, classified in class 359, subclass 495.

VII. Claims 23 and 24, drawn to a projection system comprising a Cartesian polarizing beam splitter, a color separation prism assembly having a plurality of color separating surfaces with tilt axes, and a plurality of polarization modulating reflective imagers, classified in class 359, subclass 247.

3. Claim 13 link(s) inventions I-VII. The restriction requirement between the linked inventions is subject to the nonallowance of the linking claim(s), claim 13. Upon the allowance of the linking claim(s), the restriction requirement as to the linked inventions shall be withdrawn and any claim(s) depending from or otherwise including all the limitations of the allowable linking claim(s) will be entitled to examination in the instant application. Applicant(s) are advised that if any such claim(s) depending from or including all the limitations of the allowable linking claim(s) is/are presented in a continuation or divisional application, the claims of the continuation or divisional application may be subject to provisional statutory and/or nonstatutory double patenting rejections over the claims of the instant application. Where a restriction requirement is withdrawn, the provisions of 35 U.S.C. 121 are no longer applicable. See *In re Ziegler*, 44 F.2d 1211, 1215, 170 USPQ 129, 131-32 (CCPA 1971). See also MPEP § 804.01.

4. Claim 19 link(s) inventions VI and VII. The restriction requirement between the linked inventions is subject to the nonallowance of the linking claim(s), claim 19. Upon the allowance of the linking claim(s), the restriction requirement as to the linked inventions shall be withdrawn and any claim(s) depending from or otherwise including all the limitations of the allowable linking claim(s) will be entitled to examination in the instant application. Applicant(s) are advised that if any such claim(s) depending from or including all the limitations of the allowable linking claim(s) is/are presented in a continuation or divisional application, the claims of the continuation or divisional application may be subject to provisional statutory and/or nonstatutory double patenting rejections over the claims of the instant application. Where a restriction requirement is withdrawn, the provisions of 35 U.S.C. 121 are no longer applicable. See *In re Ziegler*, 44 F.2d 1211, 1215, 170 USPQ 129, 131-32 (CCPA 1971). See also MPEP § 804.01.

5. The inventions are distinct, each from the other because of the following reasons:

Inventions I and II are related as combination and subcombination. Inventions in this relationship are distinct if it can be shown that (1) the combination as claimed does not require the particulars of the subcombination as claimed for patentability, and (2) that the subcombination has utility by itself or in other combinations (MPEP § 806.05(c)). In the instant case, the combination as claimed does not require the particulars of the subcombination as claimed because of the evidence of claims 23 and/or 24. The subcombination has separate utility such as a projection system without a plurality of imagers or recombination prism.

Inventions I and [III-V] are related as combination and subcombination. Inventions in this relationship are distinct if it can be shown that (1) the combination as claimed does not require the particulars of the subcombination as claimed for patentability, and (2) that the subcombination has utility by itself or in other combinations (MPEP § 806.05(c)). In the instant case, the combination as claimed does not require the particulars of the subcombination as claimed because of the evidence of claims 1-7,12 and 25. The subcombination has separate utility such as a projection system without a plurality of imagers or recombination prism.

Inventions I and [VI, VII] are related as combination and subcombination. Inventions in this relationship are distinct if it can be shown that (1) the combination as claimed does not require the particulars of the subcombination as claimed for patentability, and (2) that the subcombination has utility by itself or in other combinations (MPEP § 806.05(c)). In the instant case, the combination as claimed does not require the particulars of the subcombination as claimed because of the omission of the details that the color separation prism assembly includes a plurality of color separating surfaces having tilt axes, wherein the tilt axes of the color separating surfaces are perpendicular to the first axes of the beam splitter. The subcombination has separate utility such as a projection system without a plurality of imagers or recombination prism (see claim 22) or a plurality of polarization modulating imagers or a recombination prism (see claim 23) or a plurality of polarization modulating reflective imagers (see claim 24).

Inventions I and VII are related as combination and subcombination. Inventions in this relationship are distinct if it can be shown that (1) the combination as claimed does not require the

particulars of the subcombination as claimed for patentability, and (2) that the subcombination has utility by itself or in other combinations (MPEP § 806.05(c)). In the instant case, the combination as claimed does not require the particulars of the subcombination as claimed because of the omission of the details that the color separation prism assembly includes a plurality of color separating surfaces having tilt axes, wherein the tilt axes of the color separating surfaces are perpendicular to the first axes of the beam splitter or by the evidence of claims 14 and 22. The subcombination has separate utility such as a projection system without a plurality of polarization modulating imagers or a recombination prism (see claim 23), a plurality of polarization modulating reflective imagers (see claim 24) or without an illumination system having a f/# less than or equal to 2.5.

Inventions II, VI and VII are related as subcombinations disclosed as usable together in a single combination. The subcombinations are distinct from each other if they are shown to be separately usable. In the instant case, each of the inventions II, VI and VII has separate utility such as a projection system with the separate details of the other inventions. For example, the projection system of inventions I and VI has separate utility as a projection system without a plurality of imagers of invention VII, and the projection system of invention VII has separate utility as a projection system without an illumination system having a f/# less than or equal to 2.5 of inventions II or VI. See MPEP § 806.05(d).

Inventions III, IV and V are related as subcombinations disclosed as usable together in a single combination. The subcombinations are distinct from each other if they are shown to be

separately usable. In the instant case, each of the inventions III, IV and V has separate utility such as a projection system with the separate details of the other inventions. For example, the projection system of inventions III has separate utility as a projection system without the particular color separation prism details of invention IV or particular polarizing beam splitter details of Invention V, the projection system of invention IV has separate utility as a projection system without the particular polarizing beam splitter details of Invention V or projection details of invention III and the projection system of invention V has separate utility as a projection system without the particular color separation prism details of invention IV or projection details of invention III. See MPEP § 806.05(d).

6. Because these inventions are distinct for the reasons given above and have acquired a separate status in the art as shown by their different classification, or recognized divergent subject matter, or the search required for one of the inventions is not coextensive with the search for any of the remaining inventions (as stated below) restriction for examination purposes as indicated is proper.

Invention II would further require a search in class 348, subclass 745 which would not be required for inventions III-V and VII.

Invention III would further require a search in class 353, subclass 20 and class 348, subclass 744 which would not be required for inventions II and IV-VII.

Invention IV would further require a search in class 359, subclass 831 which would not be required for inventions II, III, V, VI and VII.

Invention VI would further require a search in class 359, subclass 638 which would not be required for inventions II-V and VII. Note : If application elects the invention VI, the examiner will examine invention II (claim 14) along therewith.

7. This application contains claims directed to the following patentably distinct species of the claimed invention:

A). The optical system being (1) a front projection system or (2) a rear projection system;

B). The first polarization direction being (1) a s-polarization direction or (2) a p-polarization direction; and

C). The beam splitter being a (1) 3M ABF multilayer film or (2) a wire grid.

Applicant is required under 35 U.S.C. 121 to elect a single disclosed species for prosecution on the merits to which the claims shall be restricted if no generic claim is finally held to be allowable. Currently, at least claim 13 is generic.

Applicant is advised that a reply to this requirement must include an identification of the species that is elected consonant with this requirement, and a listing of all claims readable thereon, including any claims subsequently added. An argument that a claim is allowable or that all claims are generic is considered nonresponsive unless accompanied by an election.

Upon the allowance of a generic claim, applicant will be entitled to consideration of claims to additional species which are written in dependent form or otherwise include all the limitations of an allowed generic claim as provided by 37 CFR 1.141. If claims are added after the election, applicant must indicate which are readable upon the elected species. MPEP § 809.02(a).

Should applicant traverse on the ground that the species are not patentably distinct, applicant should submit evidence or identify such evidence now of record showing the species to be obvious variants or clearly admit on the record that this is the case. In either instance, if the examiner finds one of the inventions unpatentable over the prior art, the evidence or admission may be used in a rejection under 35 U.S.C. 103(a) of the other invention.

8. Applicant is reminded that upon the cancellation of claims to a non-elected invention, the inventorship must be amended in compliance with 37 CFR 1.48(b) if one or more of the currently named inventors is no longer an inventor of at least one claim remaining in the application. Any amendment of inventorship must be accompanied by a petition under 37 CFR 1.48(b) and by the fee required under 37 CFR 1.17(I).

9. Applicant is advised that the reply to this requirement to be complete must include an election of the invention to be examined even though the requirement be traversed (37 CFR 1.143).

10. Any inquiry concerning this communication should be directed to R.D. Shafer at telephone number (703) 308-4813.

RDS

June 16, 2002

RICKY D. SHAFER
PATENT EXAMINER
ART UNIT 2872

D. Response to Restriction Requirement, July 18, 2002

S/N 09/746933 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Aastuen, et al	Examiner:	Shafer
Serial No.:	09/746933	Group Art Unit:	2872
Filed:	12/22/00	Docket No.:	810.527USI1
Title:	REFLECTIVE LCD PROJECTION SYSTEM USING A WIDE-ANGLE POLARIZING BEAM SPLITTER		

CERTIFICATE OF MAILING UNDER 37 C.F.R. §1.8

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Assistant Commissioner for Patents, Washington, DC 20231 on July 18, 2002.

Iain A. McIntyre

Name

Signature

RESPONSE TO RESTRICTION REQUIREMENT

22865

PATENT TRADEMARK OFFICE

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

In response to the restriction requirement dated June 18, 2002, Applicants hereby elect Group I, claims 1-12 and 25 with traverse.

It is stated in the Restriction Requirement that claims 13 and 19 are considered to be linking claims and neither claim is subject to the restriction. Accordingly claims 13 and 19 are still under consideration in the present case.

The Examiner also required the Applicants to elect species. Applicants respectfully assert that the species election is improper. Claims to be restricted to different species must be mutually exclusive (MPEP § 806.04(f)), and the Restriction Requirement states that a single disclosed species be selected for prosecution on the merits.

However, there are three different species choices listed in the Restriction Requirement, namely A) the optical system being either a front projection or rear projection system; B) the first polarization direction being either s-polarized or p-polarized and C) the beamsplitter being a multilayer film beamsplitter or a wire grid beamsplitter. The choices in each of A)-C) are internally mutually exclusive, for example the optical system may be either a front or a rear projection system, but not both. Thus,

each of the choices A)-C) provides a set of mutually exclusive options. However, the choice among A, B and C is not mutually exclusive. For example, if the system is a rear projection system, it does not matter whether the first polarization is s-polarization or p-polarization, and it does not matter whether the polarizer is a multilayer polarizer or a wire grid polarizer. Therefore, Applicants cannot respond with one single species elected for prosecution on the merits, but with three different, independent species.

Accordingly, Applicants understand that the Examiner has provided Applicants with three different species selections to be made, A)-C). Applicants respectfully elect, with traverse, A) the optical system being a rear projection system, B) the first polarization direction being s-polarization and C) the beamsplitter being multilayer film beamsplitter.

The Restriction Requirement indicates that only claim 13 is considered to be generic. Applicants respectfully assert that claim 19, stated in the Restriction Requirement to be a linking claim, is also generic: claim 19 does not limit the system to either a front- or rear-projector, does not limit the polarization of the first polarization component and does not limit the type of Cartesian beamsplitter.

The elected species read on linking claims 13, and 19 and claims 1, 2, 4-7, and 9-12.

Any questions regarding this communication should be directed to the undersigned attorney at 952-253-4110.

Respectfully submitted,

Altera Law Group, LLC
6500 City West Parkway – Suite 100
Minneapolis, MN 55344-7701
(952)-253-4100

Date: July 18, 2002 ,

By: I. A. McIntyre

Iain A. McIntyre
Reg. No. 40,337
IAM/vlb

E. First Office Action, October 24, 2002

OCT 30 2002

1072

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/746,933	12/22/2000	Charles L. Bruzzone	55376~~USA4A~~ US051	3760

7590 10/24/2002

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OFFICE OF INTELLECTUAL PROPERTY COUNSEL
3M INNOVATIVE PROPERTIES COMPANY

OCT 28 2002

1/24/03

YTF

DOCKETED BY

REFERRED TO

EXAMINER	
SHAFER, RICKY D	
ART UNIT	PAPER NUMBER
2872	

DATE MAILED: 10/24/2002

Please find below and/or attached an Office communication concerning this application or proceeding.

~~2 MO Response 24 Dec 02~~

3 MO Response 24 Jan 03

6 MO Response 24 April 03

PTO-90C (Rev. 07-01)

11

Office Action Summary	Application No. 09/746,933	Applicant(s) BRUZZONE ET AL
	Examiner R.D. SHAFER	Group Art Unit 2872

—The MAILING DATE of this communication appears on the cover sheet beneath the correspondence address—

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTHS MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, such period shall, by default, expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

☒ Responsive to communication(s) filed on 7/23/02.

☐ This action is **FINAL.**

☐ Since this application is in condition for allowance except for formal matters, **prosecution as to the merits is closed** in accordance with the practice under *Ex parte Quayle,* 1935 C.D. 1 1; 453 O.G. 213.

Disposition of Claims

☒ Claim(s) 1-19 AND 22-25 is/are pending in the application.

Of the above claim(s) 3, 8, 14-19 AND 22-25 is/are withdrawn from consideration.

☐ Claim(s) ______ is/are allowed.

☒ Claim(s) 1, 2, 4-7 AND 9-13 is/are rejected.

☐ Claim(s) ______ is/are objected to.

☐ Claim(s) ______ are subject to restriction or election requirement

Application Papers

☐ The proposed drawing correction, filed on ______ is ☐ approved ☐ disapproved.

☐ The drawing(s) filed on ______ is/are objected to by the Examiner

☒ The specification is objected to by the Examiner.

☒ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119 (a)-(d)

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119 (a)-(d).

☐ All ☐ Some* ☐ None of the:

☐ Certified copies of the priority documents have been received.

☐ Certified copies of the priority documents have been received in Application No. ______.

☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a))

*Certified copies not received: ______

Attachment(s)

☒ Information Disclosure Statement(s), PTO-1449, Paper No(s). 13 AND 17

☒ Notice of Reference(s) Cited, PTO-892

☐ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Interview Summary, PTO-413

☐ Notice of Informal Patent Application, PTO-152

☐ Other ______

Office Action Summary

1. Applicant's election with traverse of group I (claims 1-12 and 25), species A(2), the optical system being a rear projection system, species B(1), the first polarization direction being a s-polarization direction, and species C(1), the beam splitter being a 3M ABF multilayer film, in Paper No. 16 is acknowledged. The traversal is on the ground(s) that the species requirement is improper. This is not found persuasive because the species requirement set forth in Paper No. 15 was never intended by the examiner for applicant to elect one of the categories of A, B or C , as applicant's asserts, but was clearly intended for applicant to elect one of the subcategories from each of the categories A, B and C.

The requirement is still deemed proper and is therefore made FINAL.

2. Claims 3, 8, 14-19 and 22-25 are withdrawn from further consideration pursuant to 37 CFR 1.142(b), as being drawn to a nonelected invention and/or species, there being no allowable generic or linking claim. Applicant timely traversed the restriction (election) requirement in Paper No. 16.

3. Claim 6 is rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

In claim 6, line 2, the use of the language "each image" is vague, indefinite and/or confusing. Moreover, the above mentioned language lacks proper antecedent basis.

4. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless -

(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraphs (1), (2), and (4) of section 371© of this title before the invention thereof by the applicant for patent.

The changes made to 35 U.S.C. 102(e) by the American Inventors Protection Act of 1999 (AIPA) do not apply to the examination of this application as the application being examined was not (1) filed on or after November 29, 2000, or (2) voluntarily published under 35 U.S.C. 122(b). Therefore, this application is examined under 35 U.S.C. 102(e) prior to the amendment by the AIPA (pre-AIPA 35 U.S.C. 102(e)).

5. Claim 13 is rejected under 35 U.S.C. 102(b) as being anticipated by Gagnon et al ('028).

Gagnon et al discloses a projection system comprising a polarizing beam splitter [(22) or (24)] and a color separation prism [(24), (28) or (32)], wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note the single drawing figure.

6. Claim 13 is rejected under 35 U.S.C. 102(b) as being anticipated by Nagashima ('294).

Nagashima discloses a projection system comprising an illumination system (22,23), a polarizing beam splitter (21), a color separation and recombination prism (11), a plurality of polarization modulating imagers (12,13,14) and a projection lens (24), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note fig. 1.

7. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Bryars ('815).

Bryars discloses a projection system comprising an illumination system (10), a polarizing beam splitter (20), a color separation and recombination prism (30), a plurality of polarization modulating imagers (90,110,130) and a projection lens (140), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 1, 6 and 17 and the associated description thereof.

8. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Bryars et al ('498).

Bryars et al discloses a projection system comprising an illumination system (102,105), a polarizing beam splitter (106), a color separation and recombination prism (10), a plurality of polarization modulating imagers (110,112,114) and a projection lens (118), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 2 and 4-6 and the associated description thereof.

9. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Kuijper ('762).

Kuijper discloses a projection system comprising an illumination system (5), a pre-polarizing light (7), a polarizing beam splitter (9), a color separation and recombination prism (17), a plurality of polarization modulating imagers (11,13,15) and a projection lens (29), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 1 and 3 and the associated description thereof.

10. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Knox ('626).

Knox discloses a projection system comprising an illumination system (210,270), a polarizing beam splitter (220), a color separation and recombination prism (330), a plurality of

polarization modulating imagers (341,342,343) and a projection lens (260), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 13 and 17 and the associated description thereof.

11. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

12. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Nagashima ('294) in view of Duwaer et al ('248).

Nagashima discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer et al teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Nagashima to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Nagashima to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter of Nagashima to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Nagashima to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

13. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Bryars ('815) or Bryars et al ('498) in view of Duwaer et al ('248).

Bryars and Bryars et al each disclose all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer et al teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Bryars or Bryars et al to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Bryars or Bryars et al to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter

of Bryars or Bryars et al to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Bryars or Bryars et al to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

14. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Kuijper ('762) in view of Duwaer et al ('248).

Kuijper discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Kuijper to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter of Kuijper to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Kuijper to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

15. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Knox ('626) in view of Duwaer et al ('248).

Knox discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Knox to include a

typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Knox to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Knox as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

16. The disclosure is objected to because of the following informalities: on page 1 of the specification, applicants erroneously identified the filing date of Application Serial No. 09/312,917 as May 15, 1999 and the filing date of Provisional Application No. 60/178,973 as January 26, 2000. The correct filing date of Application Serial No. 09/312,917 is --May 17, 1999-- and the correct filing date of Provisional Application No. 60/178,973 is --January 25, 2000--.

Appropriate correction is required.

17. The oath or declaration filed on 4/27/01 is defective. A new oath or declaration in compliance with 37 CFR 1.67(a) identifying this application by application number and filing date is required. See MPEP §§ 602.01 and 602.02.

The oath or declaration is defective because applicants erroneously identified the filing date of Application Serial No. 09/312,917 as "May 15, 1999" and the filing date of Provisional Application No. 60/178,973 as "January 26, 2000". The correct filing date of Application Serial No. 09/312,917 is --May 17, 1999-- and the correct filing date of Provisional Application No. 60/178,973 is --January 25, 2000--.

18. Any inquiry concerning this communication should be directed to R.D. Shafer at telephone number (703) 308- 4813.

RDS

October 18, 2002

2872

F. Response to First Office Action, January 24, 2002

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	BRUZZONE et al.	Examiner:	Ricky D. Shafer
Serial No.:	09/746933	Group Art Unit:	2872
Filed:	December 22, 2000	Docket No.:	49837US051
Title:	REFLECTIVE LCD PROJECTION SYSTEM USING A WIDE-ANGLE POLARIZING BEAM SPLITTER		

CERTIFICATE UNDER 37 C.F.R. 1.8: The undersigned hereby certifies that this Transmittal Letter and the paper, as described herein, are being deposited in the United States Postal Service, as first class mail, with sufficient postage, in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231 on January 24, 2003.

Iain A. McIntyre
Name

Signature

AMENDMENT AND RESPONSE UNDER 37 C.F.R. §1.111

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

This paper is submitted in response to the Office Action dated October 24, 2002, setting a 3 month shortened statutory period for response.

IN THE SPECIFICATION

A marked up copy of the changes to the Specification is provided in Appendix B below.

Kindly change the first paragraph, page 2 to read as follows:

The present application is a continuation-in-part of commonly-assigned U. S. Patent Application Serial No. 09/312,917, "Reflective LCD Projection System Using Wide-Angle Cartesian Polarizing Beam Splitter", filed on May 17, 1999, which is hereby incorporated by reference. The present application also claims priority from commonly

assigned U.S. Provisional Application No. 60/178,973 entitled "Reflective LCD Projection System Using Wide-Angle Cartesian Polarizing Beam Splitter and Color Separation and Recombination Prisms", filed January 25, 2000, which is hereby incorporated by reference.

IN THE CLAIMS

A clean copy of the amended and new claims is included below. A marked up copy of the entire set of claims is included in Appendix A.

Kindly amend the claims as follows:

6. (once amended) The optical imaging system of claim 1, wherein each imager reflects a polarization modulated image, wherein the images reflected by the imagers enter the color separation and recombination prism and the prism recombines the images into a single combined image, wherein the combined image is transmitted by the Cartesian polarizing beam splitter.

11. (once amended) The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter includes a multilayer optical film.

18. (once amended) The projection system of claim 13, wherein the Cartesian polarizing beam splitter includes a multilayer optical film.

Kindly add the following new claim:

26. (new) The projection system of claim 13, wherein the Cartesian polarizing beamsplitter is disposed so that illumination light reaching the color separation prism assembly via the Cartesian polarizing beamsplitter is in substantially the same polarization state across all color bands.

REMARKS

Claims 1-19 and 22-25 are pending in the patent application. Claims 3, 8, 14-19 and 22-25 have been withdrawn from consideration. Claims 6, 11 and 18 have been amended. The amendments to claims 11 and 18 have broadened these claims to cover Cartesian polarizing beam splitters that include a multilayer optical film. New claim 26 has been added. No new matter has been introduced.

The Examiner required a supplementary declaration or oath because the originally submitted declaration listed the wrong filing dates of the priority application. The Examiner also required that the reference to the priority applications in the Specification be changed to show the correct filing dates. The Specification has been amended as required. A copy of the supplemental declaration, listing the filing dates of the priority applications as required by the Examiner, accompanies this Response.

Rejection under 35 U.S.C. § 112

Claim 6 was rejected under 35 U.S.C. § 112, second paragraph, for being vague and indefinite. Claim 6 has been amended. The amendment to claim 6 clarified the invention without narrowing the scope of the invention. It is believed that all claims comply with 35 U.S.C. § 112.

Rejections under 35 U.S.C. § 102

Claim 13 is rejected under 35 U.S.C. § 102(b) as being anticipated by Gagnon et al (U.S. Patent No. 4,425,028) (Gagnon). It is stated in the Office Action that Gagnon discloses a projection system comprising a polarizing beamsplitter (22 or 24) and a color separation prism (24, 28 or 32) wherein the axes of the polarizing beamsplitter and color separation prism are perpendicular. Gagnon teaches a projection system in which light from a light source (38) is directed to a first color selective beamsplitter or prepolarizer (22), which removes the green s-polarized light. The transmitted light propagates to the second polarizing beamsplitter (24) that reflects a portion of the light in a beam (108) to a dichroic separator (28). The dichroic separator reflects green light to a green liquid crystal light valve assembly (44). Green image light is reflected from the green liquid

crystal light valve assembly, via the dichroic separator and through the second polarizing beamsplitter to a projection lens (56). The light transmitted through the second polarizing beamsplitter from the first color selective beamsplitter is transmitted to a second dichroic separator (32) which reflects red light to a red liquid crystal light valve (48) and transmits the blue light to the blue liquid crystal light valve (50). Image light reflected by the red and blue light valve assemblies is transmitted back to the second polarizing beamsplitter and then reflected to the projection lens.

The invention of claim 13 is directed to a projection system comprising a Cartesian polarizing beam splitter (PBS), the Cartesian PBS defining a first tilt axis, and a color separation prism assembly having a second tilt axis. The Cartesian PBS and the prism assembly are arranged such that the first and second tilt axes are perpendicular to each other.

To anticipate a claim, the reference must teach every element of the claim. "A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." Verdegaal Bros. v. Union Oil Co. of California, 814 F.2d 628,631, 2 USPQ2d 1051 1053 (Fed. Cir.) 1987). "The identical invention must be shown in as complete detail as is contained in the...claim." Richardson v. Suzuki Motor Co., 868 F. 2d1226, 1236, 9 USPQ2d 1913, 1920 (Fed. Cir. 1989). Therefore, if a reference does not teach every element of the claim, then the reference does not anticipate the claim (see MPEP § 2131). Gagnon fails to teach all the elements of claim 13, and so does not anticipate claim 13.

First, Gagnon does not teach a color separation prism assembly. Instead, Gagnon teaches the use of color-sensitive polarizing beamsplitter (22 and 24) and dichroic mirrors (28 and 32) to separate the incoming white light into red, green, and blue components in particular polarization states. These elements are different from a color separation prism assembly.

The components taught by Gagnon do not constitute a color separation prism assembly, and one of ordinary skill in the art would not understand Gagnon to teach a color separation prism assembly. As evidence of this, the Examiner is referred to, for example, Bryars (U.S. Patent No. 5,986,815), also cited by the Examiner in a 102 rejection of the current claim. This reference lists different types of "color splitting

means" at col. 10, lines 45-51, including Philips prisms, X-prisms, L-prisms, beamsplitter cubes and dichroic mirrors. Bryars, therefore, distinguishes among dichroic reflectors, beamsplitter cubes and prism-type color separators. Accordingly, one of ordinary skill would understand that the term "color separation prism assembly" would not cover a combination of beamsplitter cubes and dichroic mirrors. Instead, one of ordinary skill would understand from the claim that polarization separation was performed by the Cartesian polarizing beamsplitter while color separation was performed separately by the color separation prism assembly. Gagnon's system, on the other hand, intermixes the functions of polarization separation and color separation, relying on the use of color-sensitive polarizers and dichroic mirrors. As a result, Gagnon does not teach the use of a color separation prism assembly.

Second, Gagnon fails to teach the use of a Cartesian PBS. Instead, Gagnon refers to the light passing through the various polarizing beamsplitters as p-polarized or s-polarized. A definition of a Cartesian PBS is presented in the present Application at page 7, lines 16-17, *viz.* a Cartesian PBS is one in which the polarization of the separate beams is referenced to invariant, generally orthogonal, principal axes of the PBS. Consequently, the interaction of the Cartesian PBS is <u>characterized by how the incident light is polarized with respect to the PBS axis</u>.

In contrast, the interaction of a conventional PBS, such as a McNeille PBS, is characterized <u>in terms of how the incident light is polarized with respect to the plane of incidence</u>. As an example, incidence at Brewster's angle on a conventional polarizer surface results in light being totally transmitted, without reflection, only if the polarization of the light is parallel to the plane of incidence (p-polarized). If the light is incident on the surface in a direction not completely parallel to the plane of incidence, then there exists a reflected component. On the other hand, a Cartesian PBS transmits substantially all of the incident light even if the light is not polarized parallel to the plane of incidence, so long as the light is polarized parallel to the correct axis of the polarizer. Thus, the Cartesian and non-Cartesian polarizers are fundamentally different from one another. Gagnon fails to teach the use of a Cartesian PBS.

Therefore, since Gagnon fails to teach all the elements of claim 13, Gagnon does not anticipate claim 13, and claim 13 is allowable thereover.

Claim 13 is rejected under 35 U.S.C. §102(b) as being anticipated by Nagashima (JP 63039394). Nagashima shows a polarizing beamsplitter (21) that reflects light from a light source (23) towards a color prism assembly (11).

The term "tilt axis" as defined in the present application is described in page 13, line 3 – page 14, line 23, with reference to FIGs. 2a and 2b. The tilt axis (56) of the polarizing beamsplitter (32) is the axis about which the reflecting surface is rotated to turn the surface away from normal incidence. Likewise, the tilt axes (58) of the color separation prism assembly (36) are the axes about which the reflecting surfaces of the prisms are rotated to turn the reflecting surfaces away from normal incidence. As can be seen in Nagashima's Figure 1, the tilt axes of the PBS and the turning prism project out of the plane of the figure, and are parallel. This can be compared to the embodiment of the invention illustrated in Figure 2b of the present application, in which the tilt axes are illustrated to be perpendicular. Thus, Nagashima fails to teach that the tilt axes are perpendicular.

Furthermore, Nagashima fails to teach the use of a Cartesian PBS.

Accordingly, since Nagashima fails to teach all the elements of claim 13, Nagashima fails to anticipate claim 13, and so claim 13 is allowable over Nagashima.

Claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars (U.S. Patent No. 5,986,815) (Bryars '815). Bryars '815 fails to teach all the elements of claim 13. In particular, Bryars '815 fails to teach that the tilt axes of the Cartesian PBS and the color separation prism assembly are perpendicular. Bryars '815 shows, in FIG. 1, a projection system having light source (10) that illuminates a PBS (20). The light reflected from the PBS is directed to a Philips type of prism assembly (30), formed by three prisms R, G, and B. Prism R has a reflecting surface (41b) and prism G has a reflecting surface (51b). The tilt axes of the PBS, and the two reflecting surfaces are all parallel, and lie out of the plane of the figure. Accordingly, Bryars '815 fails to teach that the tilt axes of the PBS and the color separation prism assembly are perpendicular.

Furthermore, Bryars '815 fails to teach the use of a Cartesian PBS.

Accordingly, since Bryars '815 fails to teach all the elements of claim 13, Bryars '815 fails to anticipate claim 13, and so claim 13 is allowable over Bryars '815.

Claim 13 is rejected under 35 U.S.C. § 102(e) as being anticipated by Bryars et al. (U.S. Patent No. 6,144,498) (Bryars '498). Bryars '498 fails to teach all the elements of claim 13. In particular, Bryars '498 fails to teach that the tilt axes of the Cartesian PBS and the color separation prism assembly are perpendicular. Bryars '498 shows, for example in FIG. 2, a projection system having light source (102) that illuminates a PBS (106). The light reflected from the PBS is directed to a prism assembly (10), formed by three prisms R, B, and G. Prism R has a reflecting surface (22bb) and prism B has a reflecting surface (24b). The tilt axes of the PBS, and the two reflecting surfaces are all parallel, and lie out of the plane of the figure. Accordingly, Bryars '498 fails to teach that the tilt axes of the PBS and the color separation prism assembly are perpendicular.

Furthermore, Bryars '498 fails to teach the use of a Cartesian PBS.

Accordingly, since Bryars '498 fails to teach all the elements of claim 13, Bryars '498 fails to anticipate claim 13, and so claim 13 is allowable over Bryars '498.

Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Kuijper (U.S. Patent No. 6,250,762 B1). Kuijper teaches a projection system having a light source (5) that illuminates a PBS (9). Light reflected by the PBS is directed to a color-separating element (17), comprised of three prisms 19, 21, and 23. This is referred to as a "plumbicon" prism. Blue light is reflected at the first interface (25), and red light is reflected at the second interface (27).

The tilt axes of the PBS, and the two reflecting surfaces are all parallel, and lie out of the plane of the figure. Accordingly, Kuijper fails to teach that the tilt axes of the PBS and the color separation prism assembly are perpendicular.

Furthermore, Kuijper fails to teach the use of a Cartesian PBS.

Accordingly, since Kuijper fails to teach all the elements of claim 13, Kuijper fails to anticipate claim 13, and so claim 13 is allowable over Kuijper.

Claim 13 is also rejected under 35 U.S.C. § 102(e) as being anticipated by Knox (U.S. Patent No. 6,390,626 B2). Knox teaches a projection system having a light source (210) that illuminates a PBS (220). Light reflected by the PBS is directed to various embodiments of color separating prism assemblies, including a Philips color prism (330), in FIGs. 13 and 17, prism assembly (430) in FIG. 14, and prism (530) in FIG. 16. Each

of the prism assemblies taught by Knox includes reflecting surfaces for separating and combining light of different colors.

The tilt axes of the PBS, however, and the reflecting surfaces in each prism assembly are all parallel, and lie out of the plane of the respective figures. Accordingly, Knox fails to teach that the tilt axes of the PBS and the color separation prism assembly are perpendicular.

Accordingly, since Knox fails to teach all the elements of claim 13, Knox fails to anticipate claim 13, and so claim 13 is allowable over Knox.

Since claim 13 is allowable over all the art cited in the Office Action, and since claim 13 is a generic claim, Applicants respectfully request that claims 14-18, which depend from claim 13, be reinstated in the present application for consideration.

Rejections under 35 U.S.C. § 103

Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over Nagashima in view of Duwaer et al. (U.S. Patent No. 5,146,248) (Duwaer). It is stated in the Office Action that Nagashima discloses all of the subject matter claimed, as described in the discussion of the rejection of claim 13, with the exception for explicitly stating that the illumination system has a f/# less than or equal to 2.5. It is further stated in the Office action that Duwaer teaches that it is well known to use an illumination system having an f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light, and that it would have been obvious at the time the invention was made to modify the illumination system of Nagashima to include a typically illumination system having a f/# less than or equal to 2.5 as taught by Duwaer, in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

Claims 1, 2, 4-7 and 9-12 are also rejected under 35 U.S.C. § 103(a) as being unpatentable over Bryars ('815) or Bryars (498) in view of Duwaer, and unpatentable over Kuijper in view of Duwaer and unpatentable over Knox in view of Duwaer, all for the same reasons as discussed above with respect to the rejection based on the proposed combination of Nagashima and Duwaer. All of these 103 rejections are discussed together, since they all fail for the same reasons.

Duwaer discusses a light valve projection system based on the use of three separate light sources (30, 40 and 50) emitting light at different wavelengths. Respective reflectors (34, 44, and 54) collect the light to illuminate respective transmissive light valves (36, 46 and 56). The image light transmitted through the light valves is combined in a Philips color prism (38, 48, 58), and projected using a projection lens (60). Duwaer indicates that the illumination system for this transmission-type imaging system may be as low as f/2.0.

Three criteria must be met to establish a *prima facie* case of obviousness. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference. Second, there must be a reasonable expectation of success. Finally, the prior art reference, or combination of references, must teach or suggest all the claim limitations. MPEP § 2142. Applicant respectfully traverses the rejection since the prior art fails to disclose all the claim limitations.

Claim 1 is directed to an optical imaging system that comprises an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5. A Cartesian PBS has a first tilt axis, oriented to receive the beam of light. The Cartesian PBS nominally polarizes the beam of light with respect to the Cartesian PBS. A first polarized beam of light having a first polarization direction is folded by the Cartesian PBS and a second polarized beam of light having a second polarization direction is transmitted by the Cartesian PBS. A color separation and recombination prism is optically aligned to receive one of the polarized beams of light. The prism has a second tilt axis, a plurality of color separating surfaces, and a plurality of exit surfaces. The second tilt axis is oriented perpendicularly to the first tilt axis of the Cartesian PBS so that the polarized beam is nominally polarization rotated into the opposite polarization direction with respect to the color separating surfaces and a respective beam of colored light exits through each of the exit surfaces. The system further includes a plurality of polarization modulating imagers, each imager placed at one of the exit surfaces of the color separating and recombining prism to receive one of the respective beams of colored light. Each imager can separately modulate the polarization state of the respectively incident beam of colored light.

There are several reasons why the proposed combinations of references fail to teach all the claimed elements. First, a feature of the invention of claim 1 is that the second tilt axis of the color separation and recombination prism is perpendicular to the first tilt axis of the Cartesian PBS. As is discussed above, the tilt axis is defined in the present application in FIGs. 2a and 2b, and at page 13, line 3 – page 14, line 23. In accordance with that definition, as discussed above with respect to the rejections of claim 13 under 35 U.S.C. § 102, none of Nagashima, Bryars (815), Bryars ('498), Kuijper and Knox teach that the color separating and recombining prism has a tilt axis perpendicular to the tilt axis of the PBS. Instead, each of these references teach that the tilt axis of the color separating prism is parallel to the tilt axis of the PBS. Duwaer fails to rectify this deficiency. In fact, Duwaer does not even teach the use of a PBS, since Duwaer's system is based on transmission-type liquid crystal displays. Accordingly, the proposed combinations of references all fail to teach or suggest that the tilt axes of the PBS and the color separation prism are perpendicular.

Second, although Duwaer does teach an illumination system having an f/# of 2.0, it is important to note that this is for a transmission type of light valve, and not a reflection type of light valve. Consequently, Duwaer's system simply combines the image light in the Philips prism and then projects the combined image using a projection lens. A reflection-based imaging system, on the other hand, uses a PBS to separate the reflected image light from the incoming light. This requires a PBS having a particularly wide acceptance angle in order to illuminate with an f/# less than 2.5, as is taught in the present application and the parent application, which is incorporated by reference. None of the cited references, either individually or in combination teach or suggest that it was known to use an illumination system having an f/# of 2.5 or less for a reflective imaging system.

Therefore, the proposed combinations of Nagashima, Bryars ('815), Bryars ('498), Kuijper or Knox with Duwaer all fail to teach or suggest all the elements of the invention of claim 1.

Furthermore, there would be no reasonable expectation of success, nor would there be motivation to combine the references as suggested in the Office Action. None of the prior art cited in the Office Action teaches or suggests a PBS that could efficiently

be used in a projection system with illuminating light having an f/# of 2.5 or less. Therefore, while Duwaer taught a low f/# transmissive projection system, there was no wide angle PBS that could be used in a low f/# reflective projection system. Accordingly, one of ordinary skill would have had no reasonable expectation that combining Duwaer's teachings with the projection systems taught by Nagashima, Bryars ('815), Bryars ('498), Kuijper or Knox would have resulted in a more efficient projection system.

In view of the above, Applicants respectfully assert that the proposed combinations of references fail to teach or suggest all the elements of the invention of claim 1 and that there would have been no reasonable expectation at success in producing a projection system with increased efficiency by making the proposed combinations. Accordingly, claim 1 is not obvious in view of the cited art and is patentable thereover.

Dependent claims 2, 4-7, and 9-12, which depend from independent claim 1 and further define the invention of independent claim 1, were also rejected under 35 U.S.C. §103(a) as being unpatentable over the same combinations of references. While Applicants do not acquiesce with the particular rejections to these dependent claims, it is believed that these rejections are moot in view of the remarks made in connection with independent claim 1. Therefore, dependent claims 2, 4-7 and 9-12 are also in condition for allowance.

New claim 26 is directed to a projection system where the Cartesian polarizing beam splitter is disposed so that illumination light reaching the color separation prism assembly via the Cartesian polarizing beamsplitter is in substantially the same polarization state across all color bands. This is illustrated in FIG. 2b and the description thereof. No new matter has been added. This claim depends from claim 13 which is allowable.

In view of the amendments and reasons provided above, Claims 1, 2, 4-7 and 9-13 are in condition for allowance. Applicant respectfully requests favorable reconsideration and early allowance of all pending claims. Furthermore, Applicants respectfully request that all pending claims not currently under consideration be reinstated and allowed.

If a telephone conference would be helpful in resolving any issues concerning this communication, please contact the below-signed attorney at 952-253-4110.

Respectfully submitted,

Altera Law Group, LLC

22865
PATENT TRADEMARK OFFICE

Date: January 24, 2003 By:

Iain A. McIntyre
Reg. No. 40,337
IAM/

Appendix A
Marked Up Version of the Entire Claim Set

The entire set of pending claims is provided for the Examiner's convenience.

1. (unchanged) An optical imaging system comprising:

a) an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5;
b) a Cartesian polarizing beam-splitter having a first tilt axis, oriented to receive the beam of light, wherein the Cartesian polarizing beam splitter nominally polarizes the beam of light with respect to the Cartesian beam-splitter, wherein a first polarized beam of light having a first polarization direction is folded by the Cartesian polarizing beam splitter and a second polarized beam of light having a second polarization direction is transmitted by the Cartesian polarizing beam splitter;
c) a color separation and recombination prism optically aligned to receive one of the polarized beams of light, said prism having a second tilt axis, a plurality of color separating surfaces, and a plurality of exit surfaces, wherein the second tilt axis is oriented perpendicularly to the first tilt axis of the Cartesian polarizing beam-splitter so that the polarized beam is nominally polarization rotated into the opposite polarization direction with respect to the color separating surfaces and a respective beam of colored light exits through each of the exit surfaces; and
d) a plurality of polarization modulating imagers, each imager placed at one of the exit surface of the color separating and recombining prism to receive one of the respective beams of colored light, wherein each imager can separately modulate the polarization state of the beam of colored light incident on said imagers.

2. (unchanged) The optical imaging system of claim 1, wherein the first polarization direction is nominally s-polarization and the second polarization direction is nominally p-polarization.

3. (unchanged) The optical imaging system of claim 1, wherein the first polarization direction is nominally p-polarization and the second polarization direction is nominally s-polarization.

4. (unchanged) The optical imaging system of claim 1, wherein the illumination system provides a beam of substantially pre-polarized light.

5. (unchanged) The optical imaging system of claim 1, wherein the color separation and recombination prism includes at least three exit surfaces, and the plurality of imagers includes at least three imagers, wherein each of the colored light beams is a different color and each imager receives one of the different color light beams.

6. (once amended) The optical imaging system of claim 1, wherein each imager reflects a polarization modulated image, wherein [each image enters] <u>the images reflected by the imagers enter</u> the color separation and recombination prism and the prism recombines the images into a single combined image, wherein the combined image is transmitted by the Cartesian polarizing beam splitter.

7. (unchanged) The optical imaging system of claim 6, further comprising a projection lens assembly, wherein the combined image is projected by the lens assembly onto a surface for viewing.

8. (unchanged) The optical imaging system of claim 1, wherein the optical system is a front projection system.

9. (unchanged) The optical imaging system of claim 1, wherein the optical system is a rear projection system.

10. (unchanged) The optical imaging system of claim 1, wherein the color separation and recombination prism includes a Philips prism.

11. (once amended) The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter includes a [APF] multilayer optical film.

12. (unchanged) The optical imaging system of claim 1, wherein the polarization modulating imagers include a LCOS imager.

13. (unchanged) A projection system comprising:

a) a Cartesian polarizing beam splitter, the Cartesian polarizing beam splitter defining a first tilt axis;

b) a color separation prism assembly, the prism assembly having a second tilt axis;

c) wherein the Cartesian polarizing beam splitter and the prism assembly are arranged such that the first and the second tilt axes are perpendicular to each other.

14. (unchanged) The projection system of claim 13, further comprising an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5.

15. (unchanged) The projection system of claim 13, wherein the projection system is a front projection system.

16. (unchanged) The projection system of claim 13, wherein the system is a rear projection system.

17. (unchanged) The projection system of claim 13, wherein the color separation prism assembly includes a Philips prism.

18. (once amended) The projection system of claim 13, wherein the Cartesian polarizing beam splitter includes [APF] a multilayer optical film.

19. (unchanged) A projection engine for displaying an image, the projection engine comprising:

a) a Cartesian polarizing beam-splitter having invariant, generally orthogonal principal axes including a first tilt axis; wherein the Cartesian polarizing beam splitter reflects a first polarization component beam of an incident beam of light and transmits a second polarization component beam, the polarization of the separate component beams being referenced to the principal axes; and

b) a color separating prism assembly, optically aligned to receive one of the polarization component beams, the prism assembly having a plurality of color separating surfaces having tilt axes, the tilt axes of the color separating prism assembly being perpendicular to the first tilt axes of the Cartesian polarizing beam splitter.

22. (unchanged) The projection engine of claim 19, further comprising an illumination system providing the incident beam of light, the illumination system having an f/# of at most 2.5.

23. (unchanged) The projection engine of claim 19, further comprising a plurality of imagers, wherein the prism assembly has a plurality of exit surfaces and each imager is optically aligned with respect to a corresponding exit surface.

24. (unchanged) The projection engine of claim 23,

a) further comprising a projection lens assembly;

b) wherein each imager is a polarization modulating reflective imager and the prism assembly is a color separating and recombining prism assembly;

c) wherein the prism assembly receives the one polarization component beam and separates the polarization component beam into a plurality of color beams;

d) wherein each color beam exits through a respective exit surface and a portion of the color beam is polarization modulated and reflected by the respective imager; and

e) wherein the reflected portions of the color beams re-enter the prism assembly and are recombined into a single image beam, the image beam being directed by the Cartesian polarizing beam splitter to the projection lens assembly, wherein the projection lens assembly projects an image.

25. (unchanged) The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter is a wire grid polarizer.

26. (new) The projection system of claim 13, wherein the Cartesian polarizing beamsplitter is disposed so that illumination light reaching the color separation prism assembly via the Cartesian polarizing beamsplitter is in substantially the same polarization state across all color bands.

Appendix B
Marked Up Version of Amendments to Specification

Kindly change the first paragraph, page 2 to read as follows:

The present application is a continuation-in-part of commonly-assigned U. S. Patent Application Serial No. 09/312,917, "Reflective LCD Projection System Using Wide-Angle Cartesian Polarizing Beam Splitter", filed on May 17 [5], 1999, which is hereby incorporated by reference. The present application also claims priority from commonly assigned U.S. Provisional Application No. 60/178,973 entitled "Reflective LCD Projection System Using Wide-Angle Cartesian Polarizing Beam Splitter and Color Separation and Recombination Prisms", filed January 25 [6], 2000, which is hereby incorporated by reference.

G. Final Office Action, May 9, 2003

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/746,933	12/22/2000	Charles L. Bruzzone	~~55376USA4A~~ 49837US051	3760

32692 7590 05/09/2003

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EXAMINER	
SHAFER, RICKY D	
ART UNIT	**PAPER NUMBER**
2872	

DUE DATE(S) 7/9/03 8/9/03 11/9/03

MAY 13 2003

ATTORNEY YTF

DOCKETED CP

DATE MAILED: 05/09/2003

REFERRED TO

Please find below and/or attached an Office communication concerning this application or proceeding.

2 month FR 09 JUL 03
6 month FR 09 NOV 03

Yen Florczak

MAY 15 2003

PTO-90C (Rev. 07-01)

Office Action Summary	Application No. 09/746,933	Applicant(s) BRUZZONE ET AL.
	Examiner Ricky D. Shafer	Art Unit 2872

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *31 January 2003* .

2a)☒ This action is **FINAL**. 2b)☐ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-19 and 22-26* is/are pending in the application.

4a) Of the above claim(s) *3,8,14-19 and 22-26* is/are withdrawn from consideration.

5)☐ Claim(s) ______ is/are allowed.

6)☒ Claim(s) *1,2,4-7 and 9-13* is/are rejected.

7)☐ Claim(s) ______ is/are objected to.

8)☐ Claim(s) ______ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on ______ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

11)☐ The proposed drawing correction filed on ______ is: a)☐ approved b)☐ disapproved by the Examiner.

If approved, corrected drawings are required in reply to this Office action.

12)☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. §§ 119 and 120

13)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. ______ .

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

14)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).

a) ☐ The translation of the foreign language provisional application has been received.

15)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☐ Information Disclosure Statement(s) (PTO-1449) Paper No(s) ______ .
4) ☐ Interview Summary (PTO-413) Paper No(s). ______ .
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other:

1. Newly presented claim 26 is drawn to nonelected invention V, due to the fact that the claim recites particular details of the polarizing beam splitter. Since applicant has received an action on the merits for the originally present invention, this invention has been constructively elected by original presentation for prosecution on the merits. Accordingly, claim 26 is withdrawn from consideration as being directed to a non-elected invention. See 37 CFR1.142(b) and MPEP 821.03.

2. Applicant's arguments filed 1/31/03 have been fully considered but they are not persuasive.

Applicant argues that the prior to Nagashima ('294), Bryars ('815), Bryars et al ('498) and Kuijper ('762) do not teach a Cartesian polarizing beam splitter. The examiner disagrees and is of the opinion that the polarizing beam splitter of Nagashima ('294), Bryars ('815), Bryars et al ('498) and Kuijper ('762) is inherently a Cartesian polarizing beam splitter due to the fact that the polarizing beam splitter splits an incident light into first and second substantially polarized beams, wherein the polarization states thereof are inherently referenced to some coordinate system. Note In re Ludtke, 169 USPQ 563 (CCPA 1971). In re Swinehart, 169 USPQ226 (CCPA 1971) and In re Spada, 15 USPQ 2d 1655, 1658 (Fed. Cir. 1990).

In addition, the examiner reminds applicant that an apparatus must be distinguished from the prior art in terms of structure rather than function. See In re Danley, 120 USPQ 528, 531 (CCPA 1959) and Hewlett-Packard Co. V. Bausch & Lomb Inc. 15 USPQ 2d 1525, 1528 (Fed. Cir 1990).

Applicant argues that the prior to Nagashima ('294), Bryars ('815), Bryars et al ('498), Kuijper ('762) and Knox ('626) do not teach that the axes of the polarizing beam splitter and the color separation prism are perpendicular. The examiner disagrees and is of the opinion that the respective figure(s) of Nagashima ('294), Bryars ('815), Bryars et al ('498), Kuijper ('762) and Knox ('626) clearly illustrate the axes of the polarizing beam splitter and the color separation prism being perpendicular in the same manner, as illustrated by applicant in Figures 1b and 2b.

In response to applicant's argument that there is no suggestion or motivation to combine the references Nagashima ('294), Bryars ('815), Bryars et al ('498), Kuijper ('762) or Knox ('626) in view of Duwaer et al ('248), the examiner recognizes that obviousness can only be established by combining or modifying the teachings of the prior art to produce the claimed invention where there is some teaching, suggestion or motivation to do so found either in the references themselves or <u>In The Knowledge Generally Available To One Of Ordinary Skill In The Art</u>. See <u>In re Fine</u>, 837 F.2d 1071, 5 U.S.P.Q. 2d 1596 (FED. CIR. 1988) and <u>In re Jones</u>, 958 F.2d 347, 21 U.S.P.Q. 2d 1941 (FED. CIR. 1992). In the case, the reference to Duwaer et al teaches employing illumination optics having a f/# equal to or less than 2.5, which would obviously convey to one of ordinary skill in the art the knowledge of brightness adjustability.

Furthermore, the test for obviousness is not whether the features of a secondary reference may be bodily incorporated into the structure of the primary reference, nor is it that the claimed invention must be expressly suggested in anyone or all of the references, rather, the test is what

the combined teaching of the references, as a whole, would have suggested to those of ordinary skill in the art. See In re Keller, 642 F.2d 413, 208 U.S.P.Q. 871 (CCPA 1981).

Moreover, one cannot show nonobviousness by attacking the references individually, where the rejection is based on a combination of references. See In re Merck & Co., 800 F. 2d 1091, 231 U.S.P.Q. 375 (FED. CIR. 1986) and In re Keller, 642 F. 2d 413,208 U.S.P.Q. 871 (CCPA 1981).

3. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless -
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

4. Claim 13 is rejected under 35 U.S.C. 102(b) as being anticipated by Nagashima ('294).

Nagashima discloses a projection system comprising an illumination system (22,23), a polarizing beam splitter (21), a color separation and recombination prism (11), a plurality of

polarization modulating imagers (12,13,14) and a projection lens (24), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note fig.1.

5. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Bryars ('815).

Bryars discloses a projection system comprising an illumination system (10), a polarizing beam splitter (20), a color separation and recombination prism (30), a plurality of polarization modulating imagers (90,110,130) and a projection lens (140), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 1, 6 and 17 and the associated description thereof.

6. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Bryars et al ('498).

Bryars et al discloses a projection system comprising an illumination system (102,105), a polarizing beam splitter (106), a color separation and recombination prism (10), a plurality of polarization modulating imagers (110,112,114) and a projection lens (118), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 2 and 4-6 and the associated description thereof.

7. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Kuijper ('762).

Kuijper discloses a projection system comprising an illumination system (5), a pre-polarizing light (7), a polarizing beam splitter (9), a color separation and recombination prism (17), a plurality of polarization modulating imagers (11,13,15) and a projection lens (29), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 1 and 3 and the associated description thereof.

8. Claim 13 is rejected under 35 U.S.C. 102(e) as being anticipated by Knox ('626).

Knox discloses a projection system comprising an illumination system (210,270), a polarizing beam splitter (220), a color separation and recombination prism (330), a plurality of polarization modulating imagers (341,342,343) and a projection lens (260), wherein the axes of the polarizing beam splitter and the color separation prism are perpendicular. Note figures 13 and 17 and the associated description thereof.

9. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

10. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Nagashima ('294) in view of Duwaer et al ('248).

Nagashima discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer et al teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Nagashima to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et

al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Nagashima to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter of Nagashima to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Nagashima to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

11. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Bryars ('815) or Bryars et al ('498) in view of Duwaer et al ('248).

Bryars and Bryars et al each disclose all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer et al teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Bryars or Bryars et al to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Bryars or Bryars et al to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle

and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter of Bryars or Bryars et al to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Bryars or Bryars et al to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

12. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Kuijper ('762) in view of Duwaer et al ('248).

Kuijper discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Kuijper to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in

order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 11, it is well known to employ APF multilayer polarizing beam splitters in the same field of endeavor for the purpose of enhancing the acceptance angle and/or the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the polarizing beam splitter of Kuijper to include a APF multilayer polarizing beam splitter as is commonly used and employed in the art in order to enhance the acceptance angle and/or the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Kuijper to include a LCOS imagers as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

13. Claims 1, 2, 4-7 and 9-12 are rejected under 35 U.S.C. 103(a) as being unpatentable over Knox ('626) in view of Duwaer et al ('248).

Knox discloses all of the subject matter claimed, note the above explanation, except for explicitly stating that the illumination system has a f/# less than or equal to 2.5.

Duwaer teaches it is well known to use an illumination system having a f/# less than or equal to 2.5 in the same field of endeavor for the purpose of producing a large cone of light.

Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Knox to include a typical illumination system having a f/# less than or equal to 2.5, as taught by Duwaer et al in order to increase the brightness efficiency without sacrificing contrast or desirable brightness versus contrast ratio.

As to the limitations of claim 4, it is well known to employ a prepolarizer or clean-up polarizer before a polarizing beam splitter in the same field of endeavor for the purpose of enhancing the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the illumination system of Knox to include a prepolarizer or clean-up polarizer before the polarizing beam splitter as is commonly used and employed in the art in order to enhance the contrast ratio.

As to the limitations of claim 12, it is well known to employ LCOS imagers in the same field of endeavor for the purpose of reducing unwanted depolarization of light which thereby enhances the contrast ratio. Therefore, it would have been obvious and/or within the level of one of ordinary skill in the art at the time the invention was made to modify the imagers of Knox as is commonly used and employed in the art in order to reduce unwanted depolarization of light which thereby enhances the contrast ratio.

14. **THIS ACTION IS MADE FINAL.** Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the mailing date of this final action.

15. Any inquiry concerning this communication should be directed to R.D. Shafer at telephone number (703) 308- 4813.

RDS

May 5, 2003

2872

Notice of References Cited

Application No.	Applicant(s)		
09/746,137	Cruzzone et al		
Examiner	**Group Art Unit**		
R O Sharek	2872	Page 1 of 1	

U.S. PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS
	A	6,486,997	11-2002	Bruzzone et al	—	—
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	COUNTRY	NAME	CLASS	SUBCLASS
	N						
	O						
	P						
	Q						
	R						
	S						
	T						

NON-PATENT DOCUMENTS

*		DOCUMENT (Including Author, Title, Source, and Pertinent Pages)	DATE
	U		
	V		
	W		
	X		

* A copy of this reference is not being funished with this Office action.
(See Manual of Patent Examining Procedure, Section 707.05(a).)

H. Response to Final Office Action, July 9, 2003

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	BRUZZONE et al.	Examiner:	Ricky D. Shafer
Serial No.:	09/746,933	Group Art Unit:	2872
Filed:	December 22, 2000	Docket No.:	49837US051
Title:	REFLECTIVE LCD PROJECTION SYSTEM USING A WIDE-ANGLE POLARIZING BEAM SPLITTER		

CERTIFICATE UNDER 37 C.F.R. 1.10:
'Express Mail' mailing number: EV 314776781 US
Date of Deposit: July 9, 2003
The undersigned hereby certifies that this Transmittal Letter and the paper or fee, as described herein, are being deposited with the United States Postal Service 'Express Mail Post Office To Addressee' service under 37 CFR 1.10 and is addressed to the Commissioner for Patents, Alexandria, VA 22313-1450.

By: B A Luhman
B. A. Luhman

AMENDMENT AND RESPONSE UNDER 37 C.F.R. § 1.116

Mail Stop AF
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This paper is submitted in response to the Office Action dated May 9, 2003, setting a three month shortened statutory period for response.

IN THE CLAIMS

1. (original) An optical imaging system comprising:

a) an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5;

b) a Cartesian polarizing beam-splitter having a first tilt axis, oriented to receive the beam of light, wherein the Cartesian polarizing beam splitter nominally polarizes the beam of light with respect to the Cartesian beam-splitter, wherein a first polarized beam of light having a first polarization direction is folded by the Cartesian polarizing beam splitter and a second polarized beam of light having a second polarization direction is transmitted by the Cartesian polarizing beam splitter;

c) a color separation and recombination prism optically aligned to receive one of the polarized beams of light, said prism having a second tilt axis, a plurality of color separating surfaces, and a plurality of exit surfaces, wherein the second tilt axis is oriented perpendicularly to the first tilt axis of the Cartesian polarizing beam-splitter so that the polarized beam is nominally polarization rotated into the opposite polarization direction with respect to the color separating surfaces and a respective beam of colored light exits through each of the exit surfaces; and

d) a plurality of polarization modulating imagers, each imager placed at one of the exit surface of the color separating and recombining prism to receive one of the respective beams of colored light, wherein each imager can separately modulate the polarization state of the beam of colored light incident on said imagers.

2. (original) The optical imaging system of claim 1, wherein the first polarization direction is nominally s-polarization and the second polarization direction is nominally p-polarization.

3. (withdrawn) The optical imaging system of claim 1, wherein the first polarization direction is nominally p-polarization and the second polarization direction is nominally s-polarization.

4. (original) The optical imaging system of claim 1, wherein the illumination system provides a beam of substantially pre-polarized light.

5. (original) The optical imaging system of claim 1, wherein the color separation and recombination prism includes at least three exit surfaces, and the plurality of imagers includes at least three imagers, wherein each of the colored light beams is a different color and each imager receives one of the different color light beams.

6. (previously amended) The optical imaging system of claim 1, wherein each imager reflects a polarization modulated image, wherein the images reflected by the imagers enter the color separation and recombination prism and the prism recombines the images into a single combined image, wherein the combined image is transmitted by the Cartesian polarizing beam splitter.

7. (original) The optical imaging system of claim 6, further comprising a projection lens assembly, wherein the combined image is projected by the lens assembly onto a surface for viewing.

8. (withdrawn) The optical imaging system of claim 1, wherein the optical system is a front projection system.

9. (original) The optical imaging system of claim 1, wherein the optical system is a rear projection system.

10. (original) The optical imaging system of claim 1, wherein the color separation and recombination prism includes a Philips prism.

11. (withdrawn) The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter includes a multilayer optical film.

12. (original) The optical imaging system of claim 1, wherein the polarization modulating imagers include a LCOS imager.

13. (original) A projection system comprising:

a) a Cartesian polarizing beam splitter, the Cartesian polarizing beam splitter defining a first tilt axis;

b) a color separation prism assembly, the prism assembly having a second tilt axis;

c) wherein the Cartesian polarizing beam splitter and the prism assembly are arranged such that the first and the second tilt axes are perpendicular to each other.

14. (withdrawn) The projection system of claim 13, further comprising an illumination system providing a beam of light, the illumination system having an f/# less than or equal to 2.5.

15. (withdrawn) The projection system of claim 13, wherein the projection system is a front projection system.

16. (withdrawn) The projection system of claim 13, wherein the system is a rear projection system.

17. (withdrawn) The projection system of claim 13, wherein the color separation prism assembly includes a Philips prism.

18. (withdrawn) The projection system of claim 13, wherein the Cartesian polarizing beam splitter includes a multilayer optical film.

19. (withdrawn) A projection engine for displaying an image, the projection engine comprising:

a) a Cartesian polarizing beam-splitter having invariant, generally orthogonal principal axes including a first tilt axis; wherein the Cartesian polarizing beam splitter reflects a first polarization component beam of an incident beam of light and transmits a second polarization component beam, the polarization of the separate component beams being referenced to the principal axes; and

b) a color separating prism assembly, optically aligned to receive one of the polarization component beams, the prism assembly having a plurality of color separating surfaces having tilt axes, the tilt axes of the color separating prism assembly being perpendicular to the first tilt axes of the Cartesian polarizing beam splitter.

22. (withdrawn) The projection engine of claim 19, further comprising an illumination system providing the incident beam of light, the illumination system having an f/# of at most 2.5.

23. (withdrawn) The projection engine of claim 19, further comprising a plurality of imagers, wherein the prism assembly has a plurality of exit surfaces and each imager is optically aligned with respect to a corresponding exit surface.

24. (withdrawn) The projection engine of claim 23,

a) further comprising a projection lens assembly;

b) wherein each imager is a polarization modulating reflective imager and the prism assembly is a color separating and recombining prism assembly;

c) wherein the prism assembly receives the one polarization component beam and separates the polarization component beam into a plurality of color beams;

d) wherein each color beam exits through a respective exit surface and a portion of the color beam is polarization modulated and reflected by the respective imager; and

e) wherein the reflected portions of the color beams re-enter the prism assembly and are recombined into a single image beam, the image beam being

directed by the Cartesian polarizing beam splitter to the projection lens assembly, wherein the projection lens assembly projects an image.

25. (withdrawn) The optical imaging system of claim 1, wherein the Cartesian polarizing beam splitter is a wire grid polarizer.

26. (withdrawn) The projection system of claim 13, wherein the Cartesian polarizing beamsplitter is disposed so that illumination light reaching the color separation prism assembly via the Cartesian polarizing beamsplitter is in substantially the same polarization state across all color bands.

REMARKS

Claims 1-19 and 22-26 are pending in the application. Claims 3, 8, 14-19, and 22-26 have been withdrawn from consideration.

Status of Claim 26

The Examiner has withdrawn claim 26 from consideration because it recites particular details about the polarizing beamsplitter, and therefore falls under non-elected invention V. Applicants note that claim 26 depends from claim 13, which the Examiner has designated is a linking claim, allowance of which will result in removal of the restriction requirement.

Rejections under 35 U.S.C. § 102

Claim 13 is rejected under 35 U.S.C. §102(b) as being anticipated by Nagashima (JP 63039394) and under 35 U.S.C. § 102(e) as being anticipated by Bryars (U.S. Patent No. 5,986,815) (Bryars '815), Bryars et al. (U.S. Patent No. 6,144,498) (Bryars '498), Kuijper (U.S. Patent No. 6,250,762 B1), and Knox (U.S. Patent No. 6,390,626 B2). These references were described in the response filed by Applicants on January 24, 2003.

The invention of claim 13 is directed to a projection system comprising a Cartesian polarizing beam splitter (PBS), the Cartesian PBS defining a first tilt axis, and a color separation prism assembly having a second tilt axis. The Cartesian PBS and the prism assembly are arranged such that the first and second tilt axes are perpendicular to each other.

It is stated in the Office Action that these five references clearly illustrate the axes of the polarizing beamsplitter and color separation prism as being perpendicular in the same manner as is illustrated in FIGs. 1b and 2b of the present application. The Examiner is respectfully requested to reconsider these rejections of claim 13, for the reasons provided in the following paragraphs. The arguments over the cited references presented in the prior response are maintained and incorporated herein, but not are re-presented in their entirety.

The following discussion makes reference to the marked up copies of FIGS. 1a, 1b, 2a, 2b and FIG. 1 from Bryars '815 that accompany this response.

In FIGs. 1a and 2a of the present application, the tilt axes (56 and 58) of the polarizing beamsplitter (PBS) and the color separation prism assembly are shown to be parallel. As a result of this structure, the central ray of the light propagates within the color prism assembly in a plane parallel to the figure of FIG. 1a. In other words, the central ray of the light reflected within the color prism assembly defines a plane parallel to the plane of the figure. The light reflected within the prism is illustrated in blue, and lies parallel to the x-z plane. The plane of the light reflected within the color prism is referred to hereafter as the prism reflection plane. It should be noted that the axes shown with Figs. 1a, 1b and 2b are consistent with the direction of light traveling in the device, even though the views look dissimilar.

The light reflected from the source to the color prism assembly via the PBS also defines a plane. The central ray of the light entering the PBS from the source, shown in red, and the central ray of the light reflected by the PBS to the color prism assembly, also shown in red, defines a plane, referred to hereafter as the PBS reflection plane. The PBS reflection plane also lies parallel to the plane of the figure, and is parallel to the x-z plane.

In the apparatus shown in FIGs. 1a and 2a of the present application, the PBS reflection plane and the PBS reflection plane are parallel. Note, that this results from the fact that the tilt axes are parallel.

Referring now to the embodiments illustrated in FIGs. 1b and 2b, the tilt axis (56) of the PBS and the tilt axis (58) of the color prism assembly are now perpendicular. The Examiner is respectfully requested to consider the resulting reflection planes. The PBS reflection plane, defined by the rays shown in red, lies parallel to the plane of FIG. 1b, i.e. parallel to the x-z plane. The prism reflection plane, however, lies perpendicular to the plane of FIG. 1b, since the prism assembly has been rotated. Accordingly, the prism reflection plane and the PBS reflection plane are perpendicular to each other. This may be more clearly illustrated with reference to FIG. 2b, in which the rays shown in red define the PBS reflection plane, parallel to the x-z plane, while the rays shown in blue define the prism reflection plane, parallel to the y-z plane.

This is a result of the fact that the tilt axes of the embodiment illustrated in FIG. 2b are perpendicular.

Thus, one way of understanding the differences between having the tilt axes parallel and the tilt axes perpendicular is that, when the tilt axes are parallel, then the prism reflection plane is parallel to the PBS reflection plane, and when the tilt axes are perpendicular, then the prism reflection plane is perpendicular to the PBS reflection plane.

The embodiments illustrated in FIGs. 1a, 1b, 2a and 2b of the present Specification may be compared to FIG. 1 from Bryars '815. In the figure from Bryars '815, the PBS reflection plane, defined by the rays marked in red, lies parallel to the plane of the figure. The prism reflection plane, defined by the rays marked in blue, also lies parallel to the plane of the figure. This corresponds to the embodiment illustrated in FIG. 1a of the present invention, in which the tilt axes are parallel, and does not correspond to the embodiment illustrated in FIG. 1b, in which the tilt axes are perpendicular.

Examination of each of the references shows systems similar to that shown in FIG. 1 from Bryars '815, i.e. the PBS reflection plane is parallel to the prism reflection plane, corresponding to the tilt axes being parallel. It is important to note that none of the cited references shows a system where the PBS reflection plane is perpendicular to the prism reflection plane. Consequently, none of the references teaches that the tilt axes of the PBS and the prism assembly are perpendicular.

Since the tilt axis of the PBS being perpendicular to the tilt axis of the prism assembly is an element of claim 13, none of the references teach all the elements of claim 13, and claim 13 is not anticipated by the references.

Applicants also disagree with the statement in the Office Action regarding the meaning of the term Cartesian polarizing beamsplitter. It is stated that Nagashima, Bryars '815, Bryars '498 and Kuijper inherently teach a Cartesian polarizing beamsplitter due to the fact that the polarizing beamsplitter splits an incident light into first and second substantially polarized beams, wherein the polarization stated thereof are inherently referenced to some co-ordinate system.

The term "Cartesian polarizing beamsplitter" was described in the previously filed response, where it is stated that a Cartesian PBS is one in which the polarization of the separate beams is referenced to invariant, generally orthogonal, principal axes of the PBS. The meaning of this definition was described. Applicants respectfully disagree with the statement that a polarizing beamsplitter is a Cartesian polarization beamsplitter simply because it produces first and second polarized beams that are inherently referenced to some co-ordinate system.

It is well known that the inventor is allowed to be his own lexicographer, so long as the assigned meaning is not repugnant to the term's well known usage. MPEP 2111.01. Applicants respectfully suggest that the Examiner is not applying the defined meaning of the term but is applying his own meaning of the term. Evidence for this suggestion is provided in the phrase "inherently referenced to some co-ordinate system." That is not the meaning of the phrase "Cartesian polarizing beamsplitter." Instead, the term means that the polarization of the beams is referenced to <u>principal material axes of the PBS itself</u>, and not just "<u>some</u> co-ordinate system" (emphasis added) as asserted in the Office Action. None of Nagashima, Bryars '815, Bryars '498 and Kuijper teach that the polarization of the beams formed from the PBS is referenced to the principal axes of the PBS. The co-ordinate system defined by the term Cartesian polarizing beamsplitter is one that is tied to the principal material axes of the polarizer material itself, rather than some arbitrary set of co-ordinates as is implied in the Office Action. Accordingly, none of these references teach the use of a Cartesian PBS. If this rejection is to be maintained, the Applicants request that the Examiner provide specific evidence that these references teach that the polarization of the beams produced by the PBS is referenced to the principal material axes of the polarizer material.

As a result, Nagashima, Bryars '815, Bryars '498 and Kuijper further fail to anticipate the invention of claim 13.

Rejections under 35 U.S.C. § 103

Claims 1, 2, 4-7, and 9-12 are rejected under 35 U.S.C. § 103(a) as being unpatentable over various combinations of Nagashima, Bryars '815, Bryars '498, Kuijper

and Knox in view of Duwaer et al (U.S. Patent No. 5,146,248) (Duwaer). These were all been described in the response filed on January 24, 2003.

Three criteria must be met to establish a *prima facie* case of obviousness. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference. Second, there must be a reasonable expectation of success. Finally, the prior art reference, or combination of references, must teach or suggest all the claim limitations. MPEP § 2142. Applicants respectfully traverse the rejection since the prior art fails to disclose all the claim limitations and there would be no motivation to combine the references as proposed by the Examiner.

Applicants maintain the arguments presented against the 103 rejections in the previous response. These rejections are not re-presented here in full.

In particular, claim 1 is directed to an optical imaging system comprising, *inter alia*, a Cartesian PBS having a first tilt axis and a color separation and recombination prism having a second tilt axis perpendicular to the first tilt axis. This type of configuration has been described above with reference to claim 13, where it was shown that the cited art fails to disclose a system having the first and second tilt axes perpendicular. Instead, Nagashima, Bryars '815, Bryars '498, Kuijper and Knox only show systems in which the first and second tilt axes are parallel. Furthermore, Duwaer fails to teach any PBS, since Duwaer's system is a transmissive system, in which the image light at the different color bands is combined in a color prism. Accordingly, the proposed combinations of references fail to teach or suggest all the elements of independent claim 1.

Furthermore, Applicants respectfully suggest that there would be no reasonable expectation of success to combine the references in the manner suggested in the Office Action. Modification of the systems taught by Nagashima, Bryars '815, Bryars '498, Kuijper and Knox to include an illumination system having an f/# of f/2.5 or less would require that one of ordinary skill in the art know that a PBS capable of maintaining some acceptable level of contrast with such a low f/# was available. The problems associated with using a conventional polarizer in a projection system having an f/# of 2.5 or less were known and are discussed at length in the parent application (U.S. 09/312,917),

which is incorporated by reference in the present application. Applicants respectfully suggest that, since the problem of how to achieve a wide angle polarizer was not known to one of ordinary skill, it would not be reasonable for one of ordinary skill to combine an illumination system, as taught by Duwaer, into the systems taught by Nagashima, Bryars '815, Bryars '498, Kuijper and Knox without a suitable PBS. If this rejeciton is maintained, Applicants respectfully request that the Examiner provide some evidence that one of ordinary skill in the art knew, at the time the present invention was made, that such a polarizer was available.

Dependent claims 2, 4-7, and 9-12, which depend from independent claim 1 and further define the invention of independent claim 1, were also rejected under 35 U.S.C. §103(a) as being unpatentable over the same combinations of references. While Applicants do not acquiesce with the particular rejections to these dependent claims, it is believed that these rejections are moot in view of the remarks made in connection with independent claim 1. Therefore, dependent claims 2, 4-7 and 9-12 are also in condition for allowance.

In view of the reasons provided above, it is believed that all pending claims are in condition for allowance. Applicant respectfully requests favorable reconsideration and early allowance of all pending claims. Furthermore, Applicants request immediate consideration of the claims previously not considered, due to the allowability of linking claim 13.

If a telephone conference would be helpful in resolving any issues concerning this communication, please contact Applicant's attorney of record, Iain A. McIntyre at 952-253-4110.

Respectfully submitted,

Altera Law Group, LLC

32692
PATENT TRADEMARK OFFICE

Date: July 9, 2003

By: [signature]
Iain A. McIntyre
Reg. No. 40,337
IAM/vlb

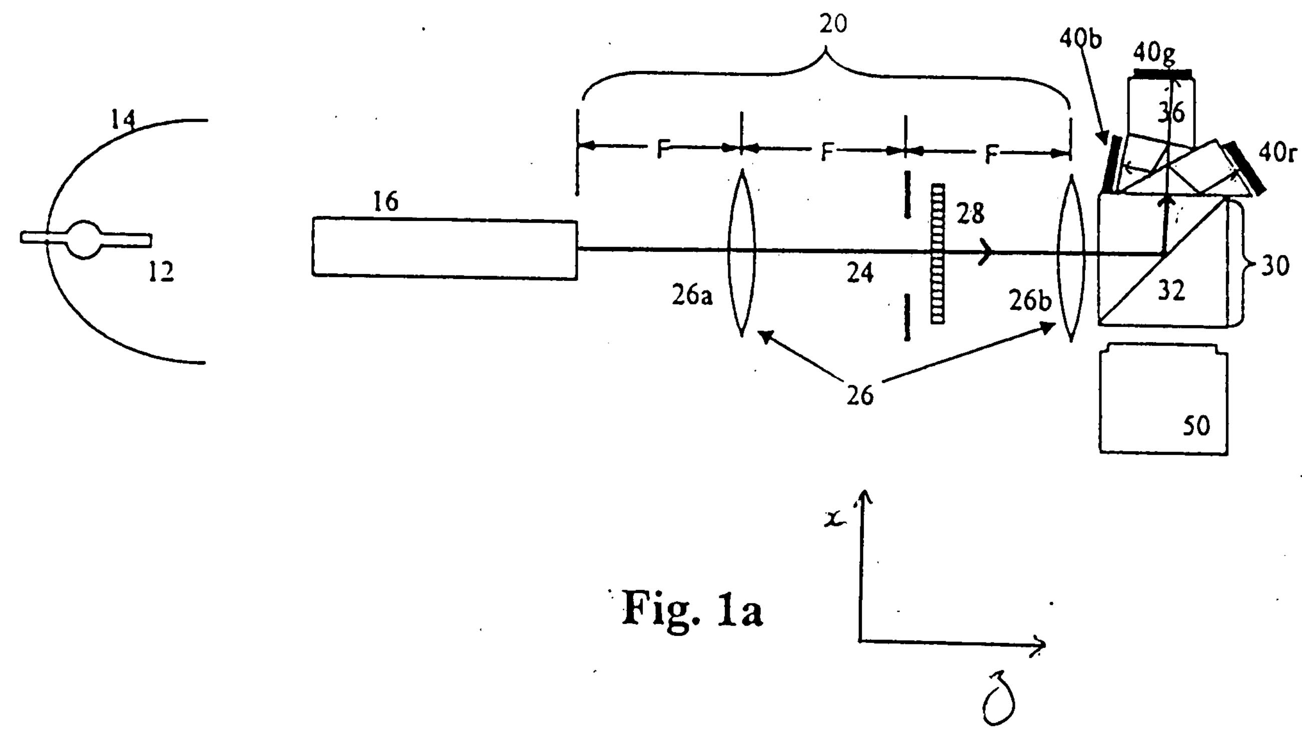

Fig. 1a

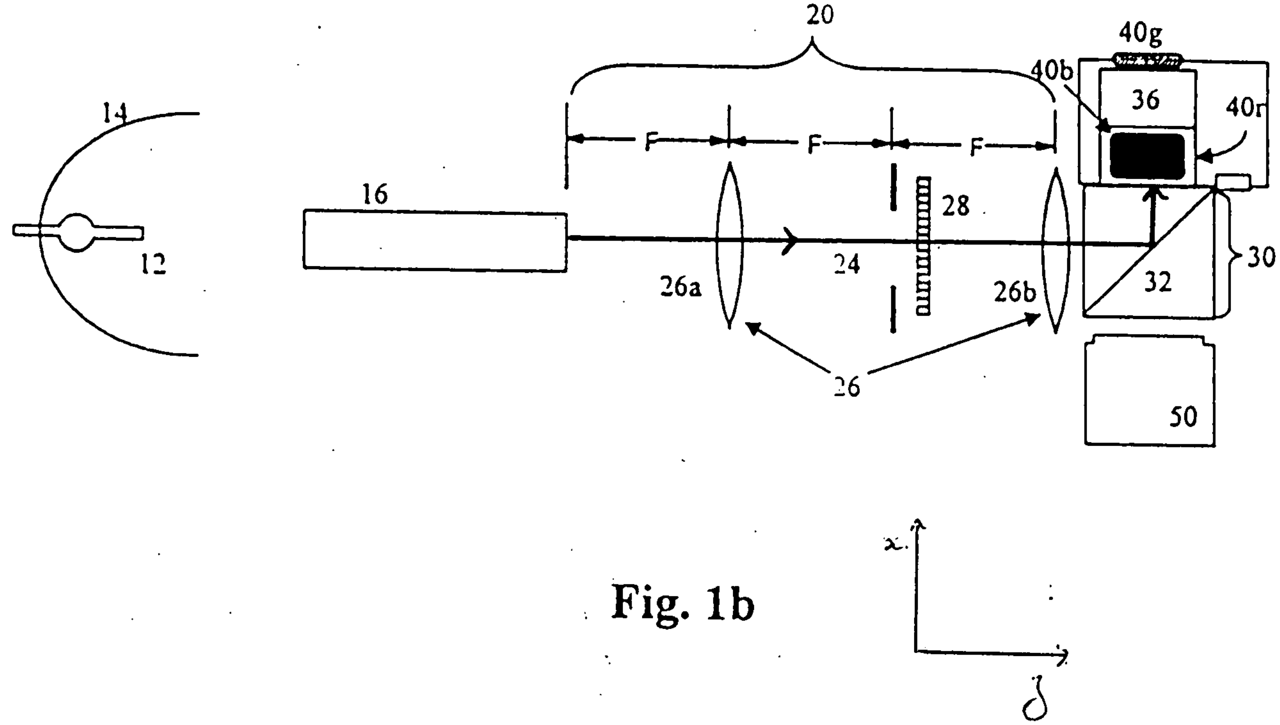

Fig. 1b

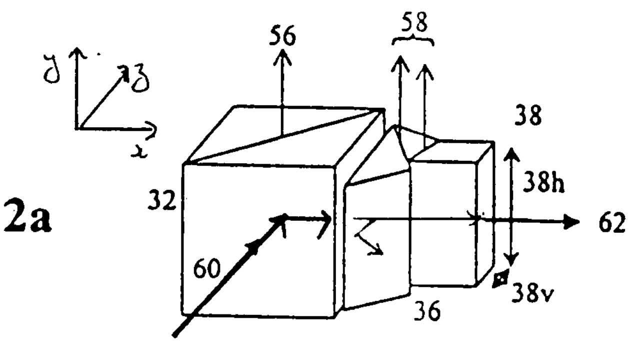

Figure 2a

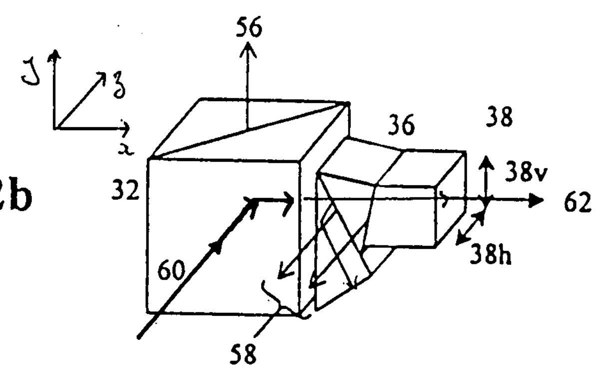

Figure 2b

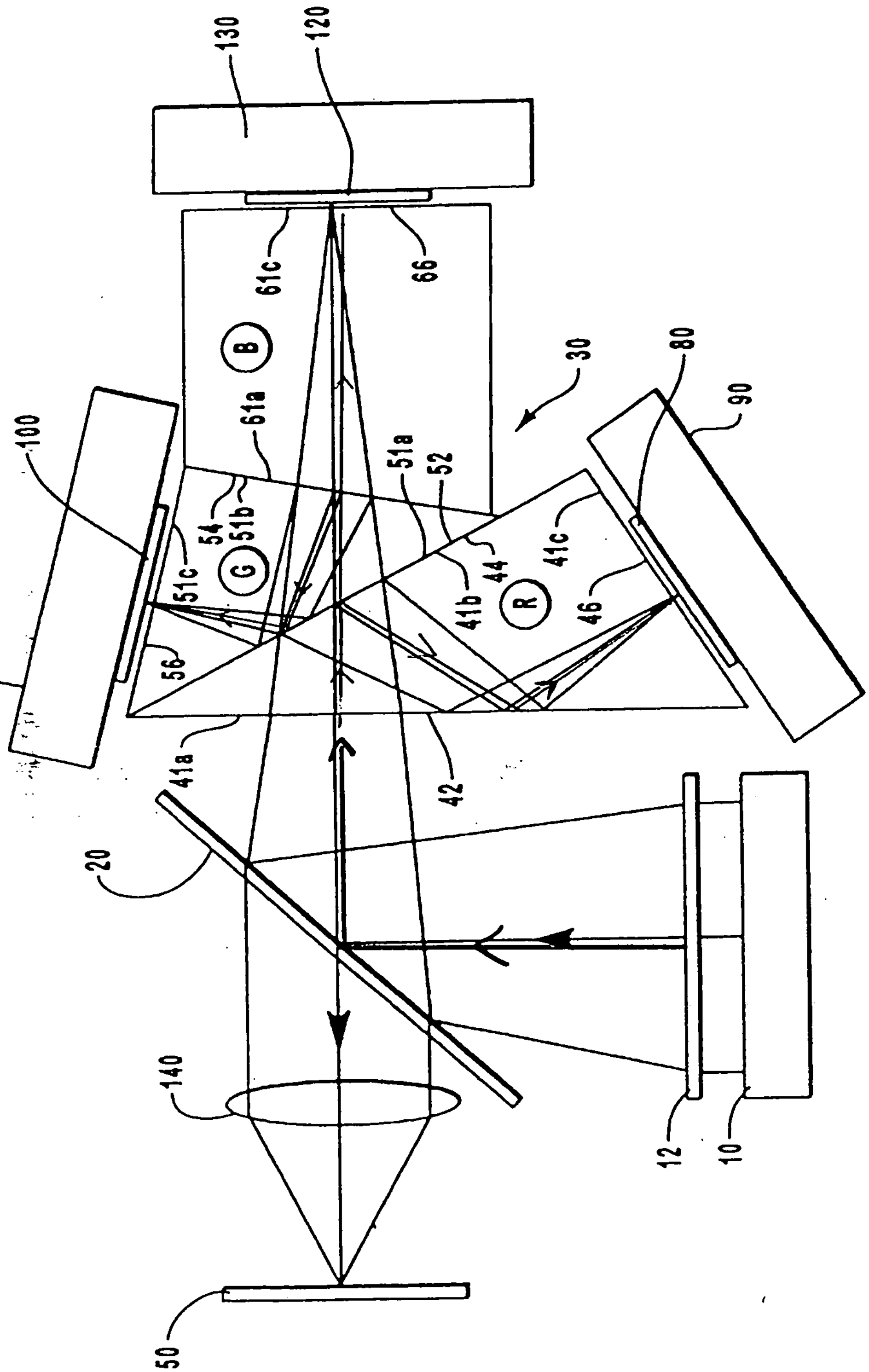
130
120
61c
66
B
30
80
90
100
61a
51a
52
54
51b
G
41c
44
R
41b
46
51c
110
56
41a
42
20
140
12
10
150

FIG. 1

I. Advisory Action, July 28, 2003

49837US051

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/746,933	12/22/2000	Charles L. Bruzzone	~~55376USA4A~~	3760

32692 7590 07/28/2003

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JUL 3 1 2003

EXAMINER
SHAFER, RICKY D

ART UNIT	PAPER NUMBER
2872	

DATE MAILED: 07/28/2003

DUE DATE(S) 8/19/03
ATTORNEY BEB
DOCKETED
REFERRED TO

Please find below and/or attached an Office communication concerning this application or proceeding.

Advisory Action	Application No.	Applicant(s)
	09/746,933	BRUZZONE ET AL.
	Examiner	Art Unit
	Ricky D. Shafer	2872

--The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

THE REPLY FILED 09 July 2003 FAILS TO PLACE THIS APPLICATION IN CONDITION FOR ALLOWANCE. Therefore, further action by the applicant is required to avoid abandonment of this application. A proper reply to a final rejection under 37 CFR 1.113 may only be either: (1) a timely filed amendment which places the application in condition for allowance; (2) a timely filed Notice of Appeal (with appeal fee); or (3) a timely filed Request for Continued Examination (RCE) in compliance with 37 CFR 1.114.

PERIOD FOR REPLY [check either a) or b)]

a) ☐ The period for reply expires ______months from the mailing date of the final rejection.

b) ☒ The period for reply expires on: (1) the mailing date of this Advisory Action, or (2) the date set forth in the final rejection, whichever is later. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the mailing date of the final rejection.
ONLY CHECK THIS BOX WHEN THE FIRST REPLY WAS FILED WITHIN TWO MONTHS OF THE FINAL REJECTION. See MPEP 706.07(f).

Extensions of time may be obtained under 37 CFR 1.136(a). The date on which the petition under 37 CFR 1.136(a) and the appropriate extension fee have been filed is the date for purposes of determining the period of extension and the corresponding amount of the fee. The appropriate extension fee under 37 CFR 1.17(a) is calculated from: (1) the expiration date of the shortened statutory period for reply originally set in the final Office action; or (2) as set forth in (b) above, if checked. Any reply received by the Office later than three months after the mailing date of the final rejection, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

1.☐ A Notice of Appeal was filed on _____. Appellant's Brief must be filed within the period set forth in 37 CFR 1.192(a), or any extension thereof (37 CFR 1.191(d)), to avoid dismissal of the appeal.

2.☐ The proposed amendment(s) will not be entered because:

(a) ☐ they raise new issues that would require further consideration and/or search (see NOTE below);

(b) ☐ they raise the issue of new matter (see Note below);

(c) ☐ they are not deemed to place the application in better form for appeal by materially reducing or simplifying the issues for appeal; and/or

(d) ☐ they present additional claims without canceling a corresponding number of finally rejected claims.

NOTE: _____.

3.☐ Applicant's reply has overcome the following rejection(s): _____.

4.☐ Newly proposed or amended claim(s) _____ would be allowable if submitted in a separate, timely filed amendment canceling the non-allowable claim(s).

5.☒ The a)☐ affidavit, b)☐ exhibit, or c)☒ request for reconsideration has been considered but does NOT place the application in condition for allowance because: *of the reasons clearly set forth in Paper No. 23*.

6.☐ The affidavit or exhibit will NOT be considered because it is not directed SOLELY to issues which were newly raised by the Examiner in the final rejection.

7.☐ For purposes of Appeal, the proposed amendment(s) a)☐ will not be entered or b)☐ will be entered and an explanation of how the new or amended claims would be rejected is provided below or appended.

The status of the claim(s) is (or will be) as follows:

Claim(s) allowed: _____.

Claim(s) objected to: _____.

Claim(s) rejected: _____.

Claim(s) withdrawn from consideration: _____.

8.☐ The proposed drawing correction filed on _____ is a)☐ approved or b)☐ disapproved by the Examiner.

9.☐ Note the attached Information Disclosure Statement(s)(PTO-1449) Paper No(s). _____.

10.☐ Other: _____

Ricky D. Shafer
2872

APPENDIX 3

REFERENCES RELIED UPON BY THE EXAMINER

A. JP Patent Publication 63039394 (Nagashima).

B. U.S. Patent No. 5,986,815 (Bryars '815).

C. U.S. Patent No. 6,144,498 (Bryars '498).

D. U.S. Patent No. 6,250,762 B1 (Kuijper).

E. U.S. Patent No. 6,390,626 B2 (Knox).

APPENDIX 3

A. JP Patent Publication 63039294 (Nagashima)

CLIPPEDIMAGE= JP363039294A

PAT-NO: JP363039294A

DOCUMENT-IDENTIFIER: JP 63039294 A

TITLE: VIDEO PROJECTING DEVICE

PUBN-DATE: February 19, 1988

INVENTOR-INFORMATION:
NAME
NAGASHIMA, YOSHITAKE

ASSIGNEE-INFORMATION:

NAME	COUNTRY
CANON INC	N/A

APPL-NO: JP61183027

APPL-DATE: August 4, 1986

INT-CL (IPC): H04N009/31

ABSTRACT:

PURPOSE: To miniaturize a device and to reduce a work for maintenance by inversely using a color separation optical system such as the one which is used for tri-color color separation for a usual television camera.

CONSTITUTION: A luminous flux emitted from a white light source 23 is projected in a collimation lens 22 to be a parallel luminous flux and goes towards the light division face of polarization BS 21, where S component are reflected, and becomes a straight polarizing light. The straight polarizing light is projected in the projection face 11a of a color separation prism 11 and separated from a color component light to be projected in the respective liquid crystal display elemets 12∼14, where it is

space-modulated according to a video signal, and then reflected by reflection mirrors 15∼17 so as to pass through the liquid crystal display elements 12∼14 from the opposite direction again. And since the liquid crystal display elements have the quality of birefringence, the straight polarizing light face of the luminous flux is made to rotate to emit in propotion to the video signal after a round trip in the elements. The strainght polarizing light of the respective components are composed during retrograding through an optical path and emitted from the projection face 11a of the color separation optical system 11, and meanwhile the components obtained by rotating the polarizing face by 90° against a projected light passes through the polarization BS 21 to be projected on a screen 25 by a projection lens 24.

⑲日本国特許庁（JP）　⑪特許出願公開
⑫公開特許公報（A）　昭63-39294
⑤Int.Cl.⁴　識別記号　庁内整理番号
H 04 N 9/31　7060-5C
㊸公開 昭和63年(1988) 2月19日
審査請求 未請求 発明の数 1 （全4頁）

㊿発明の名称 ビデオ・プロジェクション装置

㉑特 願 昭61-183027
㉒出 願 昭61(1986) 8月4日

⑫発 明 者 長 島 良 武 神奈川県川崎市高津区下野毛770番地 キヤノン株式会社玉川事業所内
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⑭代 理 人 弁理士 丸島 儀一

明細書

1．発明の名称

ビデオ・プロジェクション装置

2．特許請求の範囲

（1）ダイクロイック膜により各色成分光に分解する色分解光学系の各出射部相当側に映像信号で駆動される液晶表示素子と反射体とを夫々順置し、前記色分解光学系の入射部相当側に入射光を所定の偏光状態にすると共に光路を分割する光路分割手段を配置し、更に前記光路分割手段で分割された光路の一方に照明手段、他方に投影レンズを配置して、前記照明手段からの光が前記光路分割手段で偏光された後、前記色分解光学系を介して前記各液晶表示素子と反射体に至り、反射体から光路を逆行した各色成分光は合成されて前記投影レンズから投影されることを特徴とするビデオ・プロジェクション装置。

3．発明の詳細な説明

〔産業上の利用分野〕

本発明は、ビデオ画像をスクリーン上に投影するためのプロジェクション装置に関し、殊に光束の空間変調に2次元液晶表示素子を使用した装置に関する。

〔従来の技術〕

最近、プロジェクション型のテレビ受像器が急速に普及してきており、公共施設のみならず家庭でも見られる様になってきている。この種の装置は、赤（R）緑（G）青（B）の各色成分光に対応する3本の高輝度陰極線管に映出された色成分画像を投影レンズでスクリーンに投影してそこで合成し、元の色彩の画像を表示する様にしている。第2図はビデオ・プロジェクション装置の概要を示している。1，2，3は夫々R，G，Bに対応する陰極線管で、R，G，Bの映像信号が各々入力されるR，G，Bのドライブ回路4，5，6により駆動される。7，8，9は投影レンズで、陰極線管7，8，9の前方にスクリーン10にピントを合わせて夫々配置される。尚、本図では投影レンズを単レンズで示したが、実際には諸収差補正のために複数枚のレンズから構成されるのが普通である。

第2図からでも予想される様にプロジエクション装置は装置自体が大型となるのが大きな欠点であり、また高価になり易い。更に投影レンズとスクリーンの距離を変えると、各投影レンズの光軸のコンバージエンス調整あるいは陰極線管像の幾何学的歪みの補正を行うなどメインテナンスの手間を要する欠点があった。

〔発明が解決しようとしている問題点〕

本発明は上記欠点を除去し、特に小型でメインテナンス作業を軽減した装置の提供を目的とする。

そしてこの目的を達成するために、通常テレビカメラの3色色分解に使われる様な色分解光学系を逆に使用し、色分解光学系の各出射部相当側に映像信号で駆動される2次元液晶表示素子と反射体とを夫々順置し、前記色分解光学系の入射部相当側に入射光を所定の偏光状態にすると共に光路を分割する光路分割手段を配置し、更に前記光路分割手段で分割された光路の一方に照明手段、他方に投影レンズを配置するものである。

〔実施例〕

以下、第1図に従って本発明の一実施例を説明する。まず11は3色色分解光学系で、第1プリズム11A、第2プリズム11B、第3プリズム11Cを具え、11aがいわゆる入射面、11b, 11c, 11dが各色成分光の出射面に相当する。第1プリズムAの第2面11eには青を反射しそれより長波長域を透過させるダイクロイツク干渉薄膜が蒸着されている。第1プリズム11Aと第2プリズム11Bの間には空隙が置かれ、又第2プリズム11Bと第3プリズム11Cの間の11f面には赤反射緑透過のダイクロイツク干渉薄膜が蒸着されている。従って、入射面11aに白色光が入射したと仮定すると、面11eで青色光は反射され、面11aで内面全反射して出射11bへ向い、面11eを透過した光の内、面11fで反射した赤色光は空隙に接する面で内面反射して出射面11cへ向い、面11fを透過した緑色光は出射面11dへ向う。尚、3色色分解光学系はダイクロイツク膜を蒸着したプリズム・ブロツクを組合せて構成する他に、周知の様に板状ダイクロイツクミラーを組合せて構成しても良い。

12, 13, 14は順に青色成分の映像、赤色成分の映像、緑色成分の映像を表示する2次元液晶素子である。素子自体の構成は周知であるから説明を省く。これら液晶表示素子12, 13, 14は色分解光学系の出射面11b, 11c, 11dに接着されている。15, 16, 17は誘電体の反射鏡で液晶表示素子12, 13, 14の裏面に設けられている。

18, 19, 20は液晶表示素子の駆動回路で、例えばNTSC信号からカラーデコーダされたB, R, Gの映像信号が夫々入力され、この信号に応じて各液晶表示素子12, 13, 14を駆動する。

21は偏光ビーム・スプリツター（以下、偏光BSと云う）で色分解光学系11の設定光軸O上に配置する。22はコリメーシヨンレンズで、偏光BS21で分岐された光軸上に配置し、更にコリメーシヨンレンズのほぼ焦点上にハロゲンランプの様な白色光源23を配置する。24は投影レンズで、偏光BS21を経由した光軸にその光軸を一致させて配置する。25はスクリーンで、スクリーン25と各液晶表示素子12, 13, 14は投影レンズ24に関して共役となる様に調整される。

以上の構成で、白色光源23を発した光束はコリメーシヨンレンズ22へ入射して平行光束となり、偏光BS21の光分割面へ向いS成分が反射し、直線偏光々となる。直線偏光々は色分解プリズム11の入射面11aへ入射し、既に説明した通り色成分光に分解されて各液晶表示素子12, 13, 14へ入射し、そこで映像信号に応じて空間変調され、反射鏡15, 16, 17で反射して再び液晶表示素子12, 13, 14を逆方向から通過する。ここで液晶表示素子は複屈折性を有するので、光束は素子内の往復後、直線偏光面が映像信号に比例して回転して出射し、これら各色成分の直線偏光光が光路を逆行する内で合成されて色分解光学系11の入射面11aから射出し、偏光面が入射光に対し90°回転した成分が今度は偏光BS21を通過し、投影レンズ24でスクリーン25へ投影される。

〔効　果〕

以上述べた本発明によれば、各々陰極線管と投

影レンズを配置する場合に比較して遥かに小型で軽量となる効果があり、また各色成分光は合成された後、投影される構成を採用しているので、コンバージョンのミスが発生することなく、スクリーンまでの距離を変えた場合でも投影レンズのフォーカシングを取り直すだけで済むなど操作が簡便となる。また映像表示器として液晶を使っているので、陰極線管の様な幾何歪がなくなる効果もある。

更に偏光BSを使って照明光路と投光光路を分割し、また光を色分解光学系内を往復させて色の分解、合成を行っているので、光源の光の利用効率が高まる利点がある。

4. 図面の簡単な説明

第1図は本発明の実施例を示す光学断面図、第2図は従来例を示す平面図。

図中、

11は色分解光学系、

12・13・14は液晶表示素子、

15・16・17は反射鏡、

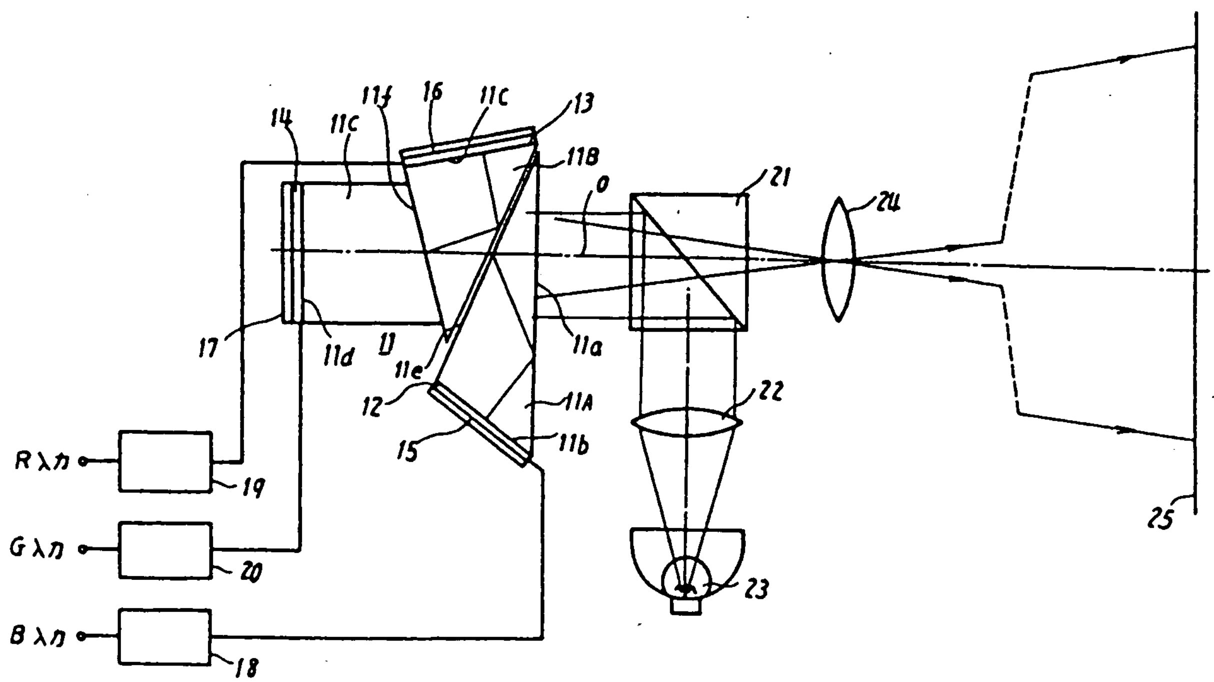
21は偏光BS、

23は白色光源、

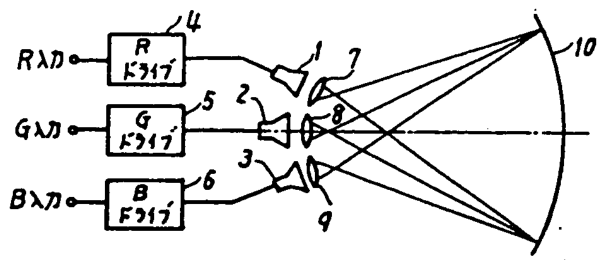
24は投影レンズである。

出願人　キヤノン株式会社
代理人　丸島儀一

第1図



第2図



B. U.S. Patent No. 5,986,815 (Bryars '815)

US005986815A

United States Patent [19]
Bryars

[11] Patent Number: 5,986,815
[45] Date of Patent: Nov. 16, 1999

[54] SYSTEMS, METHODS AND APPARATUS FOR IMPROVING THE CONTRAST RATIO IN REFLECTIVE IMAGING SYSTEMS UTILIZING COLOR SPLITTERS

[75] Inventor: Brett Bryars, Santa Rosa, Calif.

[73] Assignee: Optical Coating Laboratory, Inc., Santa Rosa, Calif.

[21] Appl. No.: 09/079,891

[22] Filed: May 15, 1998

[51] Int. Cl.⁶ G02B 27/14

[52] U.S. Cl. 359/634; 359/256; 359/637; 359/494; 349/5; 349/8; 349/9; 353/31; 353/33

[58] Field of Search 359/634, 637, 359/638, 494, 495, 250, 256, 259; 349/5, 8, 9, 18, 119; 353/31, 33, 34

[56] References Cited

U.S. PATENT DOCUMENTS

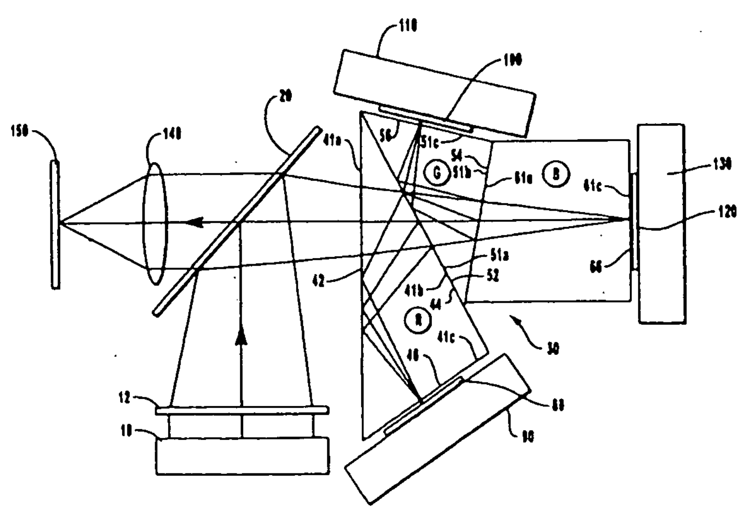
4,408,839	10/1983	Wiener-Avnear	350/347
4,583,825	4/1986	Buzak	350/335
5,005,952	4/1991	Clark et al.	350/335
5,044,732	9/1991	Kimura et al.	359/53
5,115,305	5/1992	Baur et al.	358/60
5,124,818	6/1992	Conner et al.	359/53
5,124,841	6/1992	Oishi	359/487
5,130,826	7/1992	Takanashi et al.	359/72
5,134,507	7/1992	Ishii	359/94
5,150,237	9/1992	Iimura et al.	359/73
5,157,523	10/1992	Yamagishi et al.	359/41
5,184,237	2/1993	Iimura et al.	359/63
5,231,522	7/1993	Sumiyoshi	359/53
5,245,451	9/1993	Wu et al.	359/55
5,250,214	10/1993	Kanemoto et al.	252/299.01
5,251,068	10/1993	Oshima et al.	359/634
5,264,951	11/1993	Takanashi et al.	359/53
5,267,029	11/1993	Kurematsu et al.	358/60
5,270,804	12/1993	Lach	358/62
5,285,268	2/1994	Nakagaki et al.	348/760
5,305,146	4/1994	Nakagaki et al.	359/634
5,325,137	6/1994	Konno et al.	353/63
5,327,270	7/1994	Miyatake	359/63
5,347,382	9/1994	Rumbaugh	359/84
5,379,135	1/1995	Nakagaki et al.	359/40
5,380,459	1/1995	Kanemoto et al.	252/299.01
5,387,991	2/1995	Mitsutake et al.	359/93
5,398,081	3/1995	Jones	348/742
5,400,179	3/1995	Ito	359/588
5,440,414	8/1995	Kersey et al.	359/250
5,453,859	9/1995	Sannohe et al.	359/63
5,459,593	10/1995	Ootaki	359/40
5,462,621	10/1995	Ishii	156/229
5,576,854	11/1996	Schmidt et al.	359/40
5,579,138	11/1996	Sannohe et al.	359/63
5,579,159	11/1996	Ito	359/487
5,594,591	1/1997	Yamamoto et al.	349/5
5,621,486	4/1997	Doany et al.	348/756
5,625,491	4/1997	von Gunten et al.	359/487
5,644,432	7/1997	Doany	359/634
5,658,060	8/1997	Dove	353/33
5,676,854	10/1997	Inui et al.	216/24
5,777,789	7/1998	Chiu et al.	359/494
5,777,796	7/1998	Burstyn	359/634

Primary Examiner—Loha Ben
Attorney, Agent, or Firm—Workman, Nydegger & Seeley

[57] ABSTRACT

Methods and apparatus for enhancing the performance of reflective LCD systems. The high-contrast color-splitting prism system utilizes a "double-pass" prism assembly. Polarized light enters the prism assembly, is color-split and is emitted as separate colors to reflective imagers which reflect each color in accord with a desired image. The reflected light is passed, once again, through the prism assembly where the separate colors converge and the convergent light is emitted to a projection lens for display of the image on a screen. At least one zero-incidence waveplate compensator is positioned between one reflective imager and the prism assembly. The waveplate compensator effectively decreases the unwanted polarized light entering the prism assembly for the second pass-through, thereby increases the polarization purity of the light that is emitted from the prism assembly to the projection lens to yield a high-contrast projection image.

70 Claims, 23 Drawing Sheets



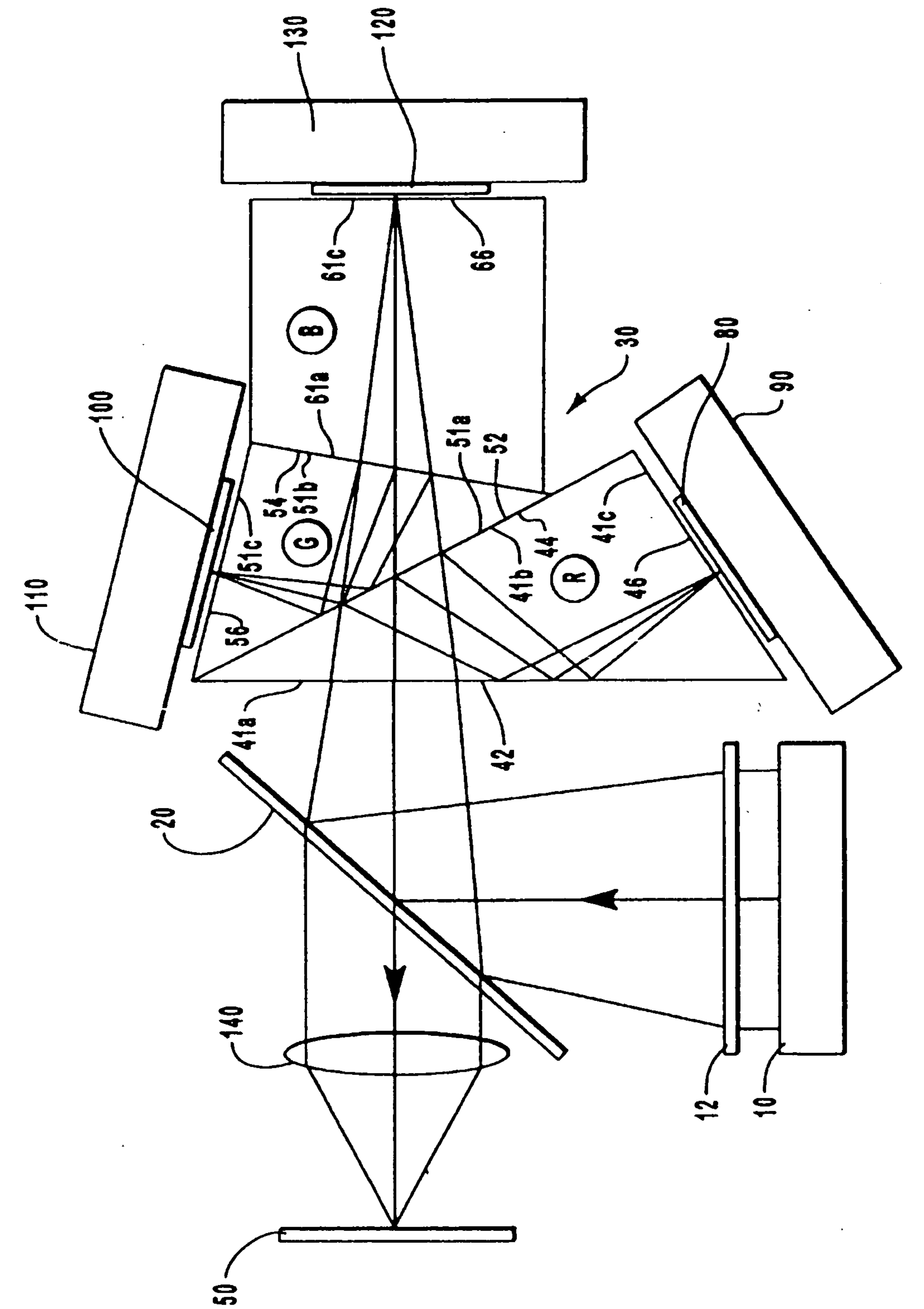

130
120
61c
66
B
30
80
90
100
61a
51a
52
54
51b
G
41c
44
41b
R
46
110
51c
56
41a
42
20
140
12
10
150

FIG. 1

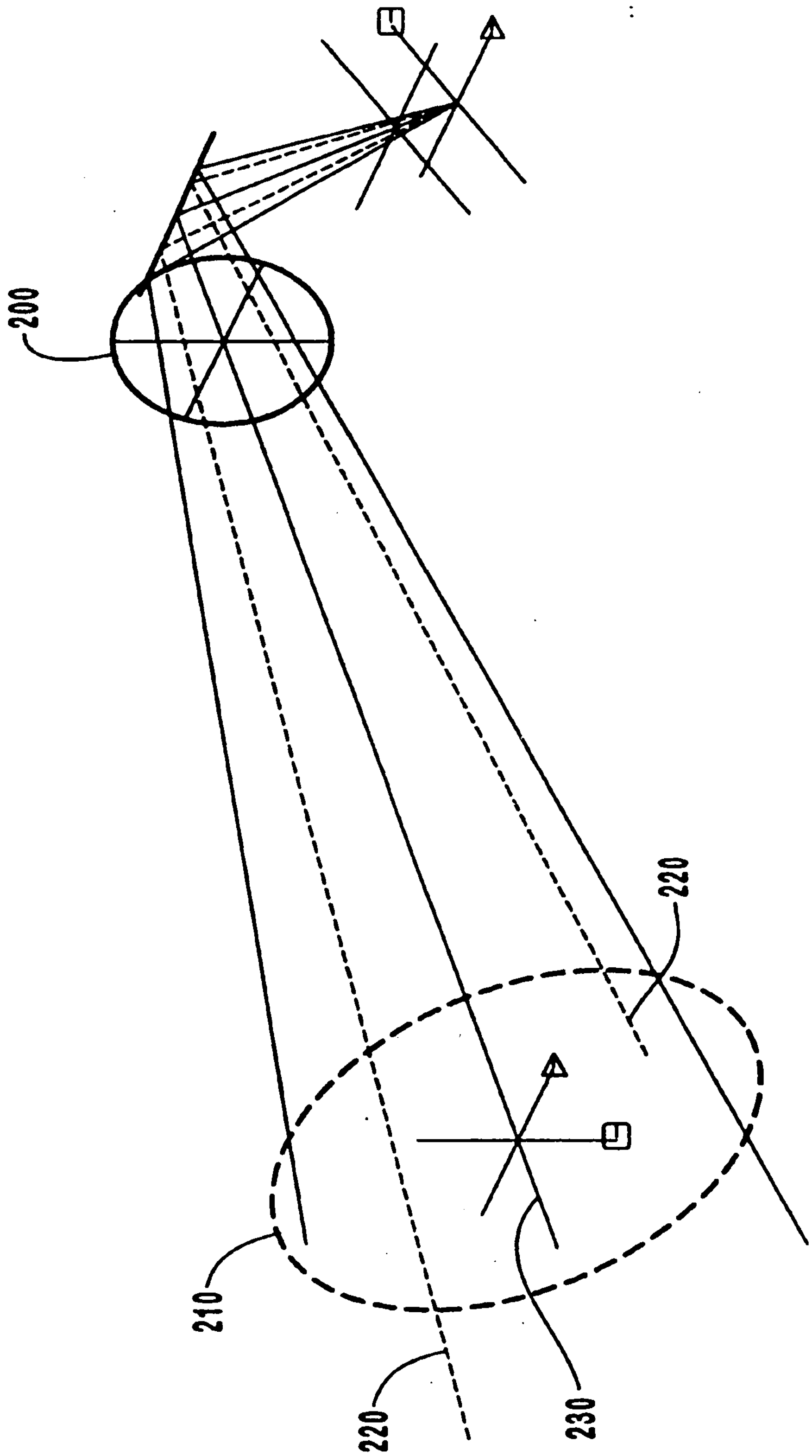


FIG. 2

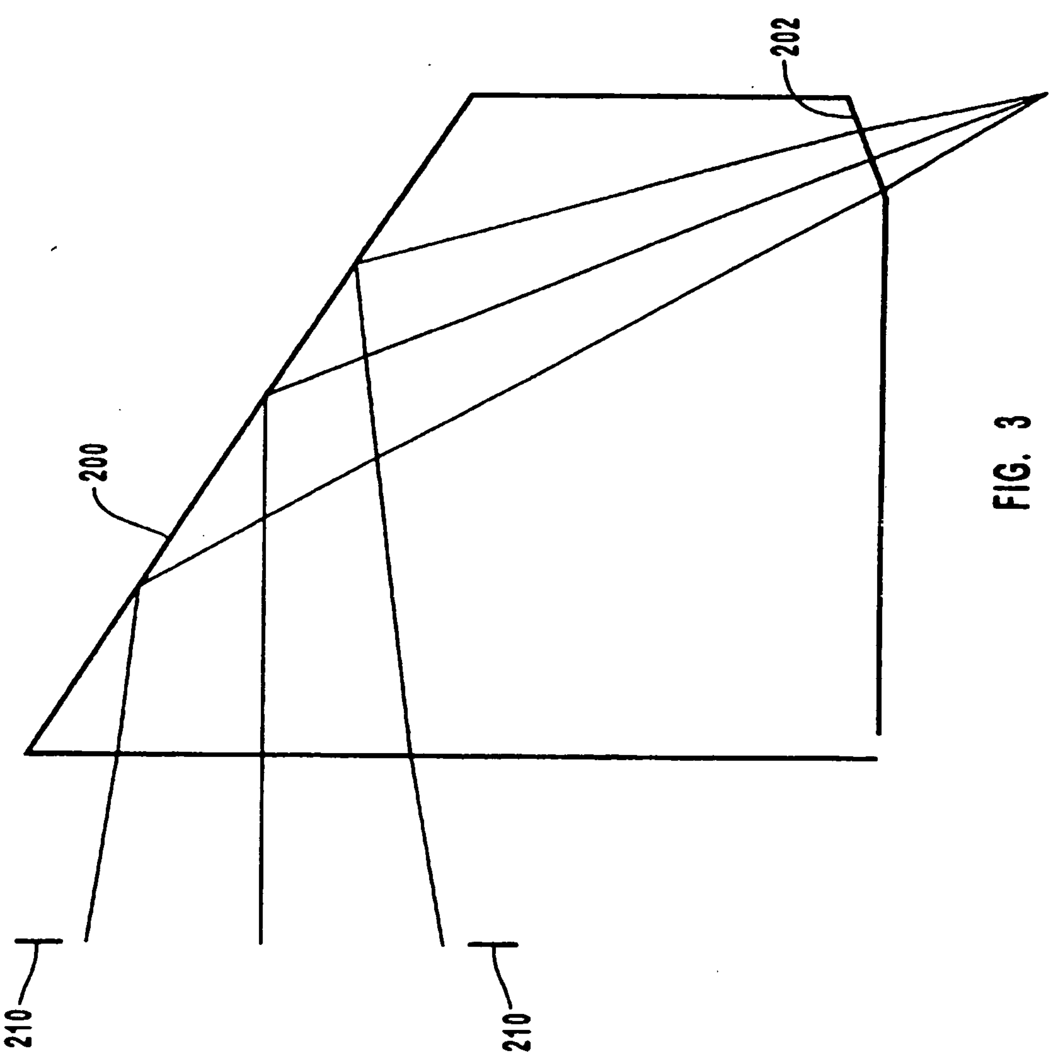


FIG. 3

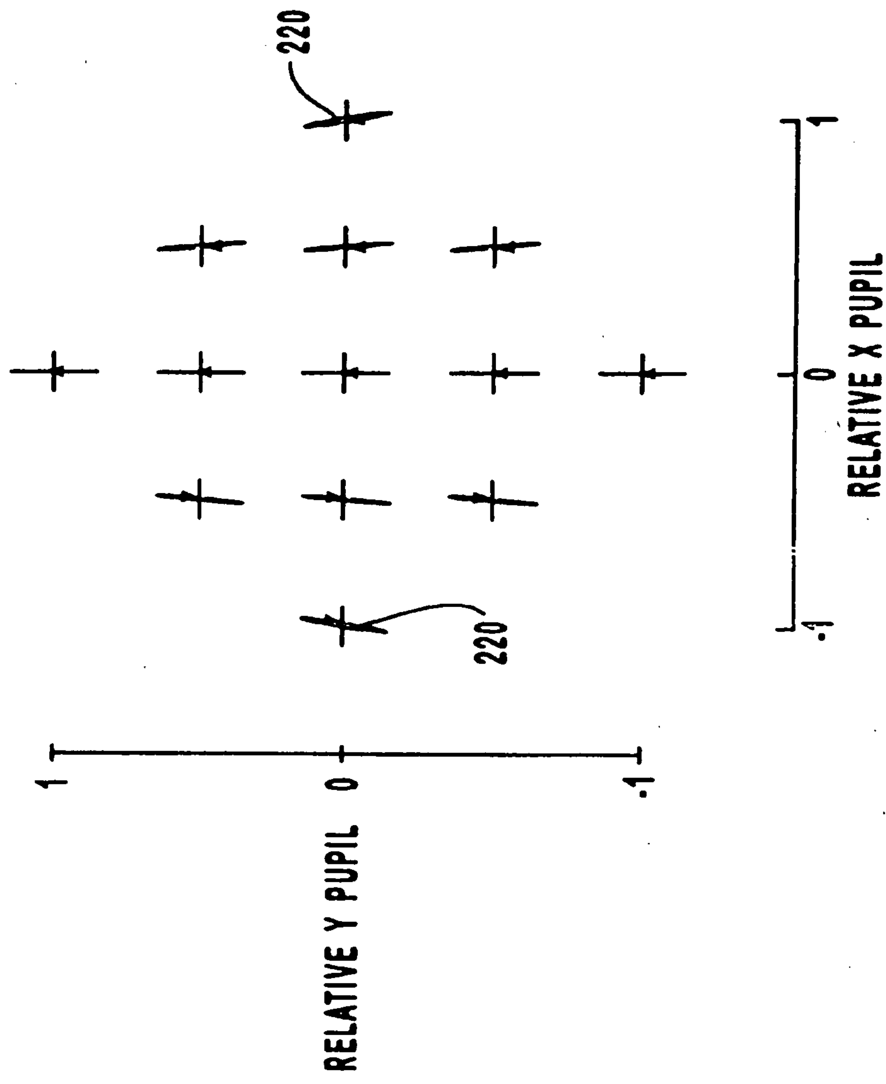


FIG. 4

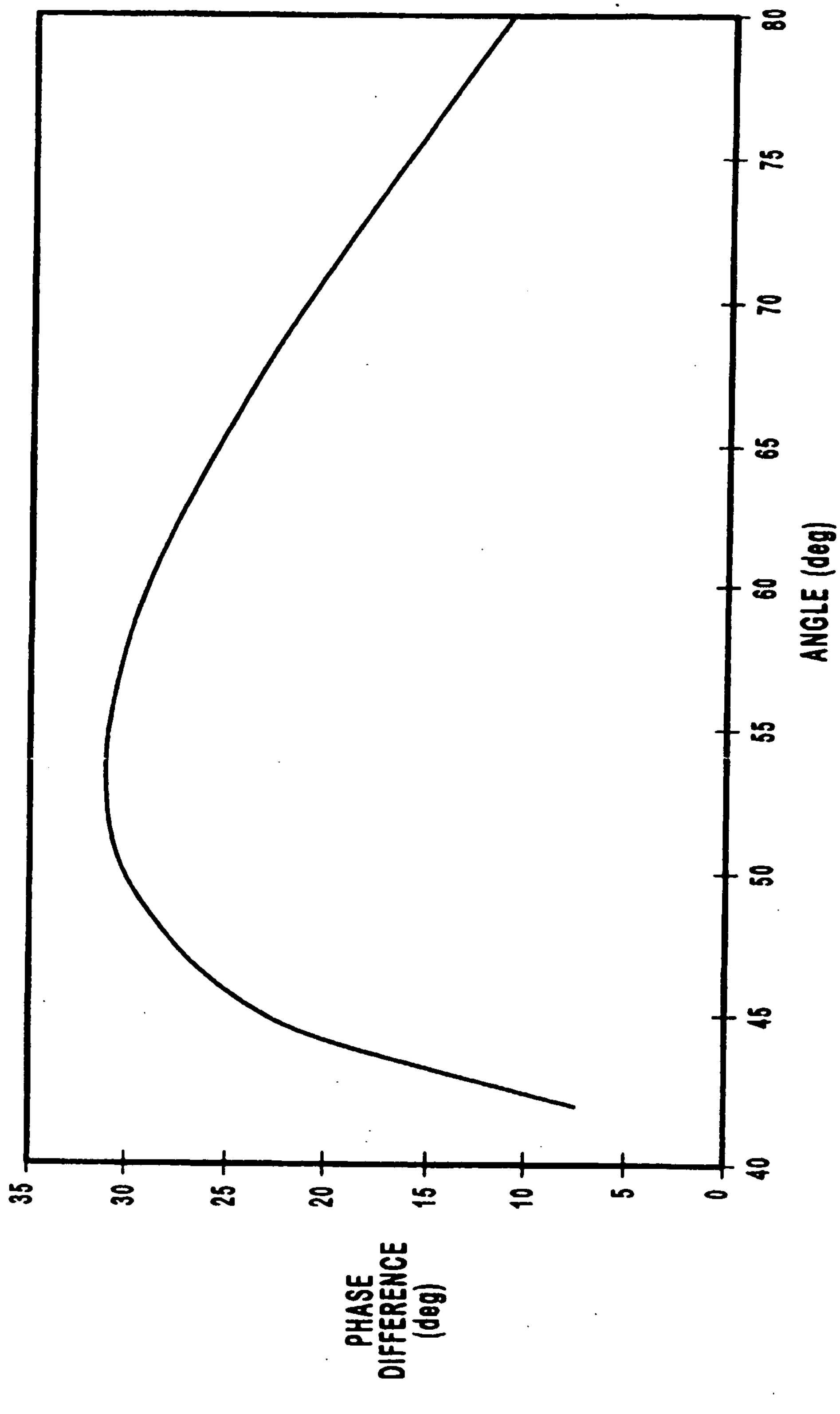

PHASE
DIFFERENCE
(deg)
35
30
25
20
15
10
5
0
40
45
50
55
60
65
70
75
80
ANGLE (deg)

FIG. 5

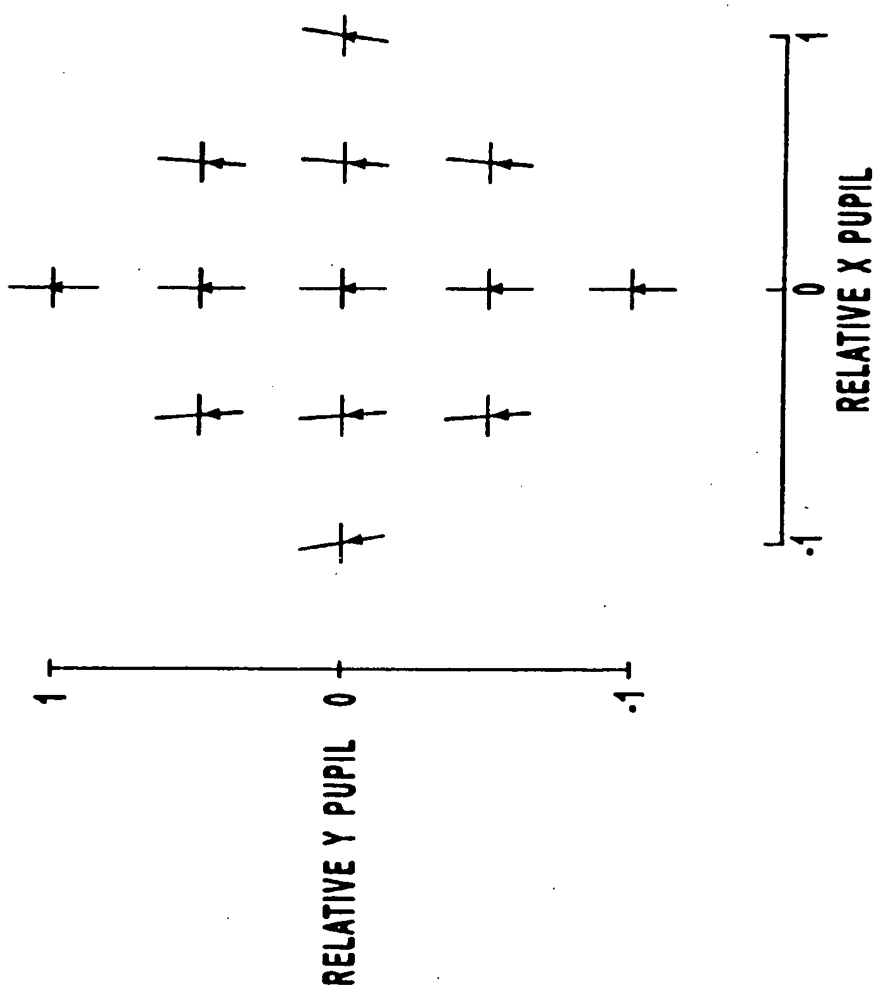
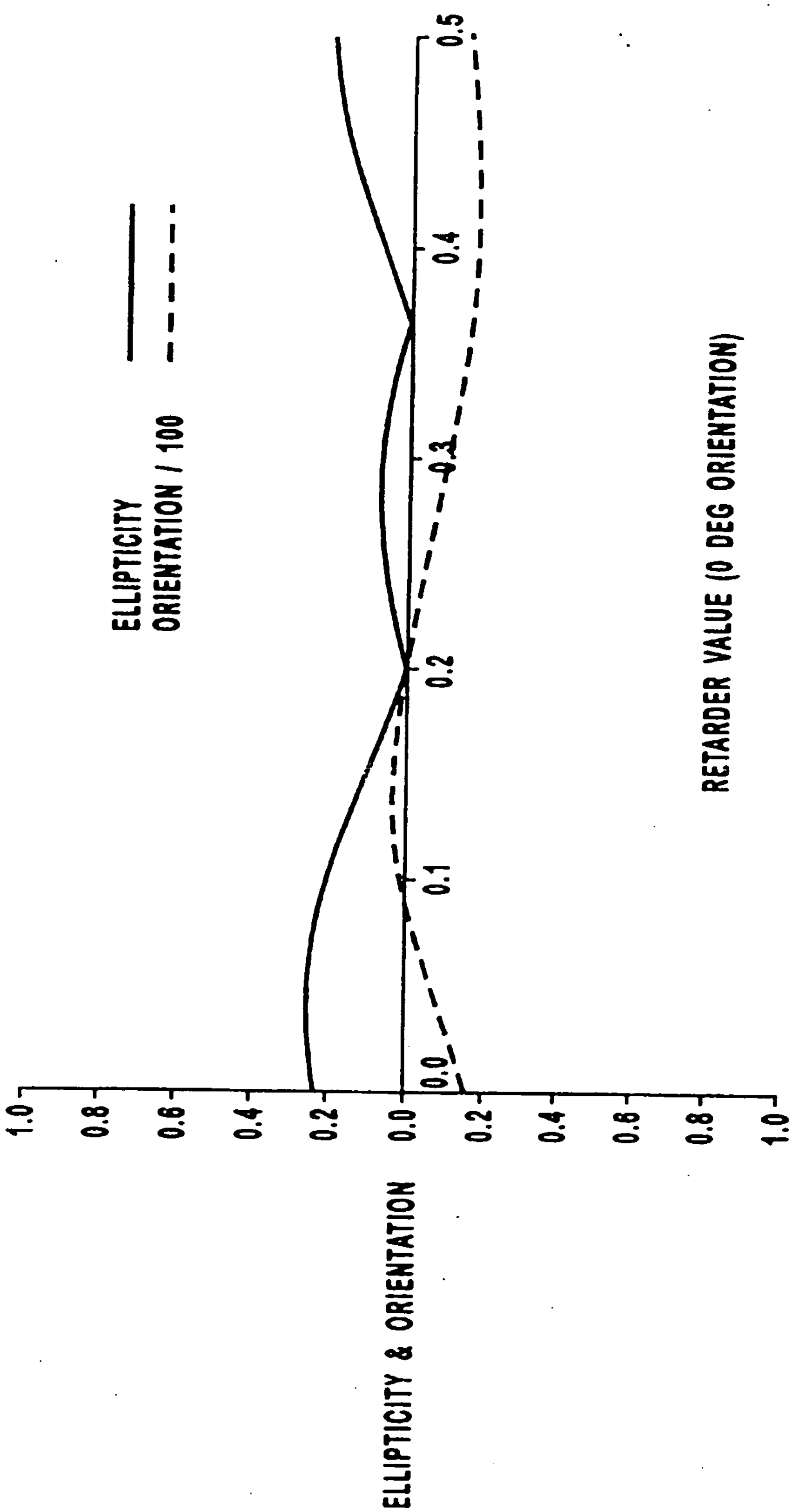


FIG. 6



ELLIPTICITY
ORIENTATION / 100
RETARDER VALUE (0 DEG ORIENTATION)
ELLIPTICITY & ORIENTATION
0.0
0.1
0.2
0.3
0.4
0.5
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

FIG. 7

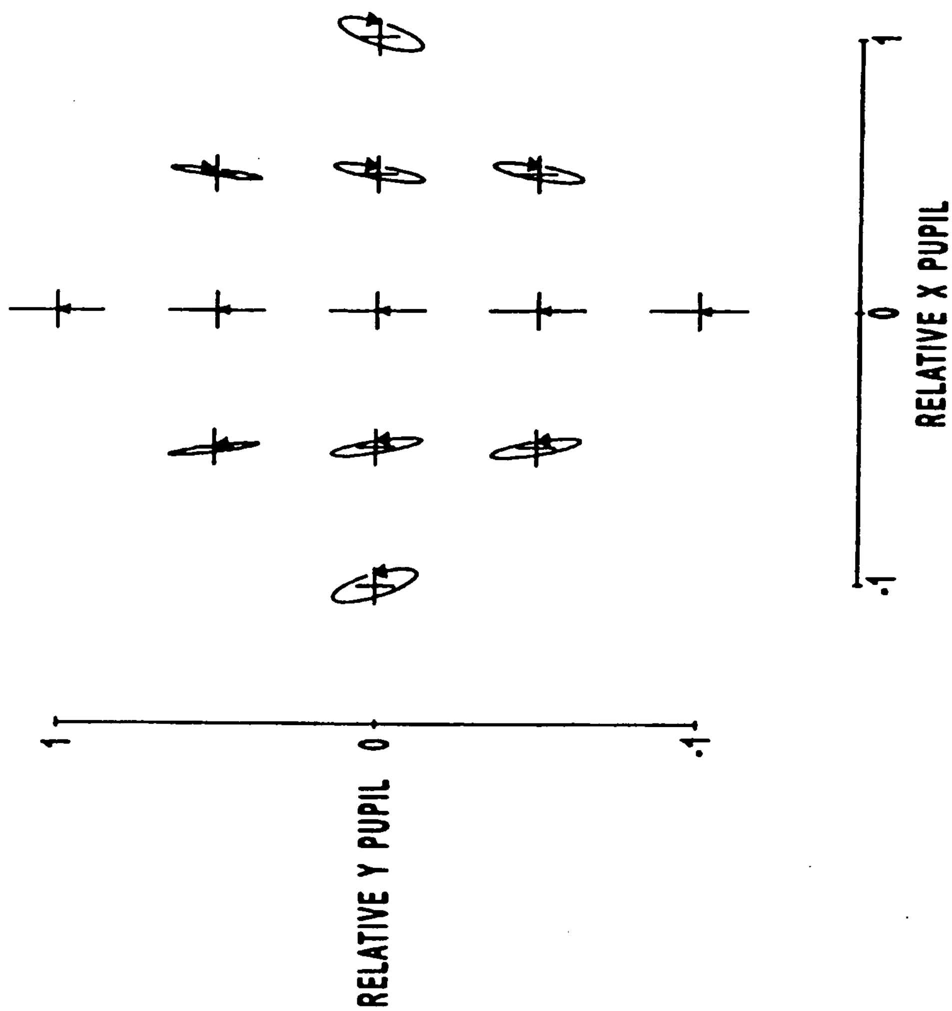


FIG. 8

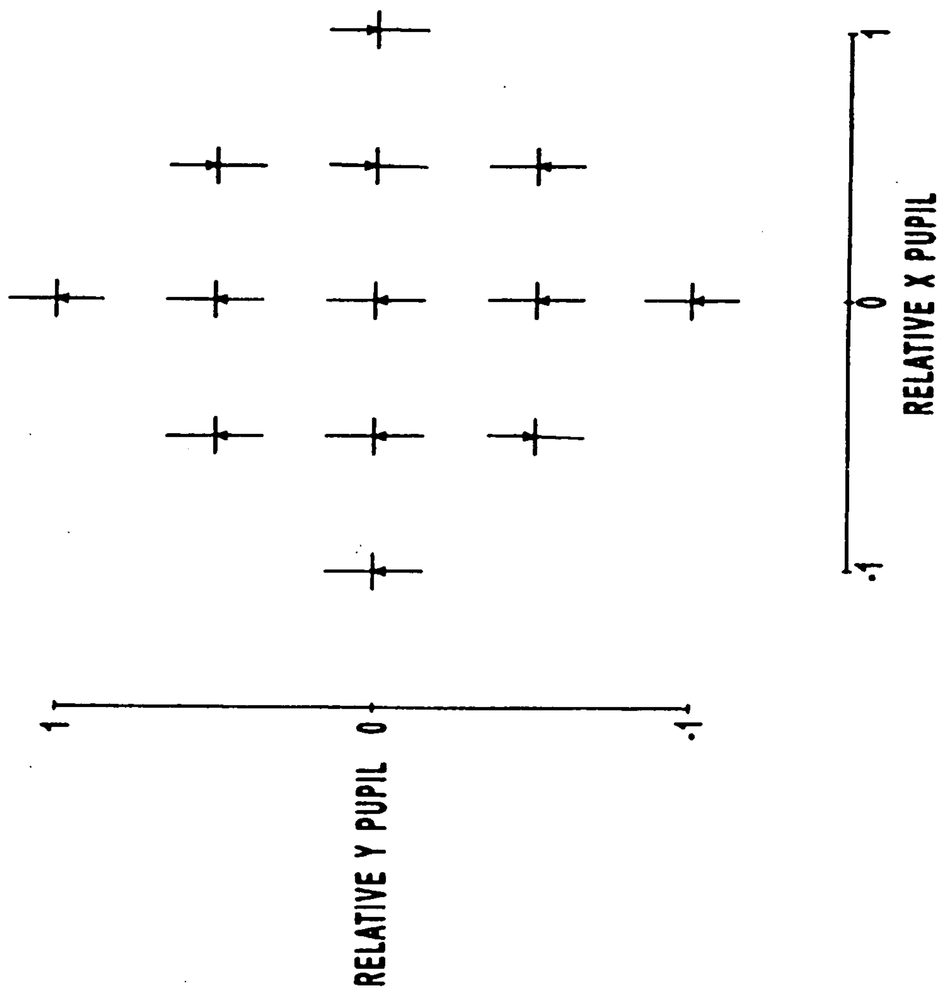
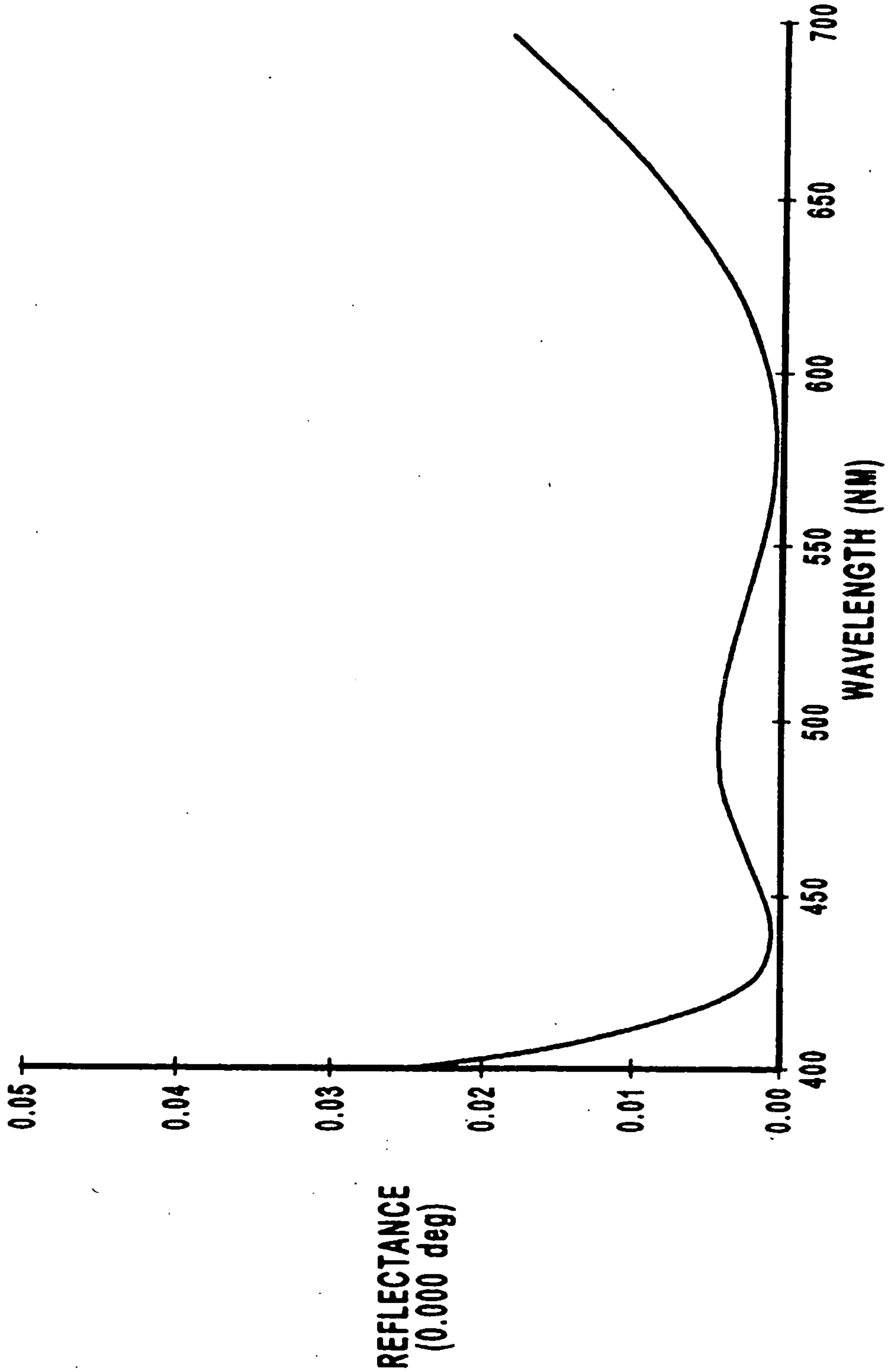


FIG. 9



0.05
0.04
0.03
0.02
0.01
0.00
REFLECTANCE
(0.000 deg)
400
450
500
550
600
650
700
WAVELENGTH (NM)

FIG. 10

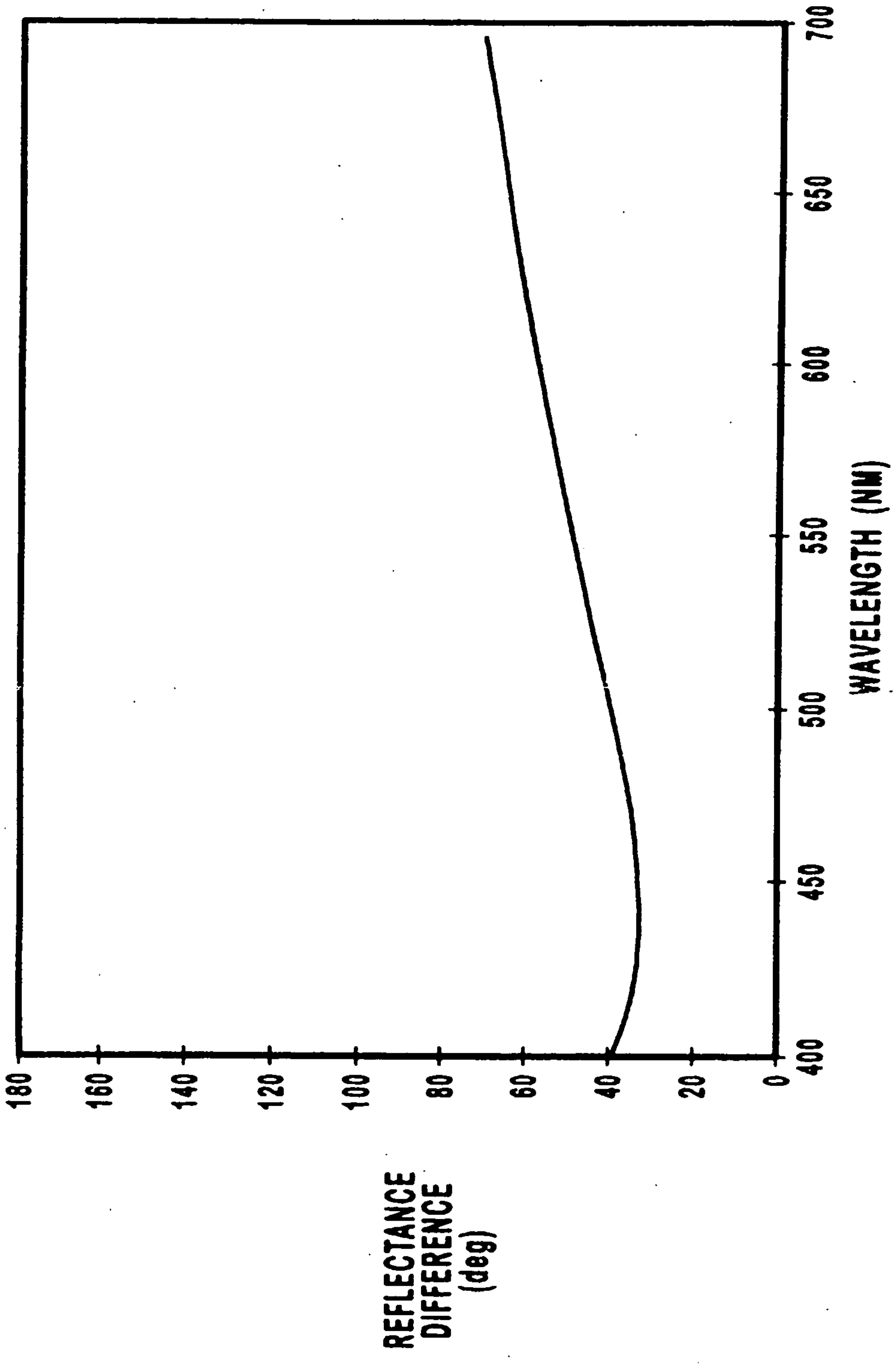

REFLECTANCE DIFFERENCE (deg)
0
20
40
60
80
100
120
140
160
180
400
450
500
550
600
650
700
WAVELENGTH (NM)

FIG. 11

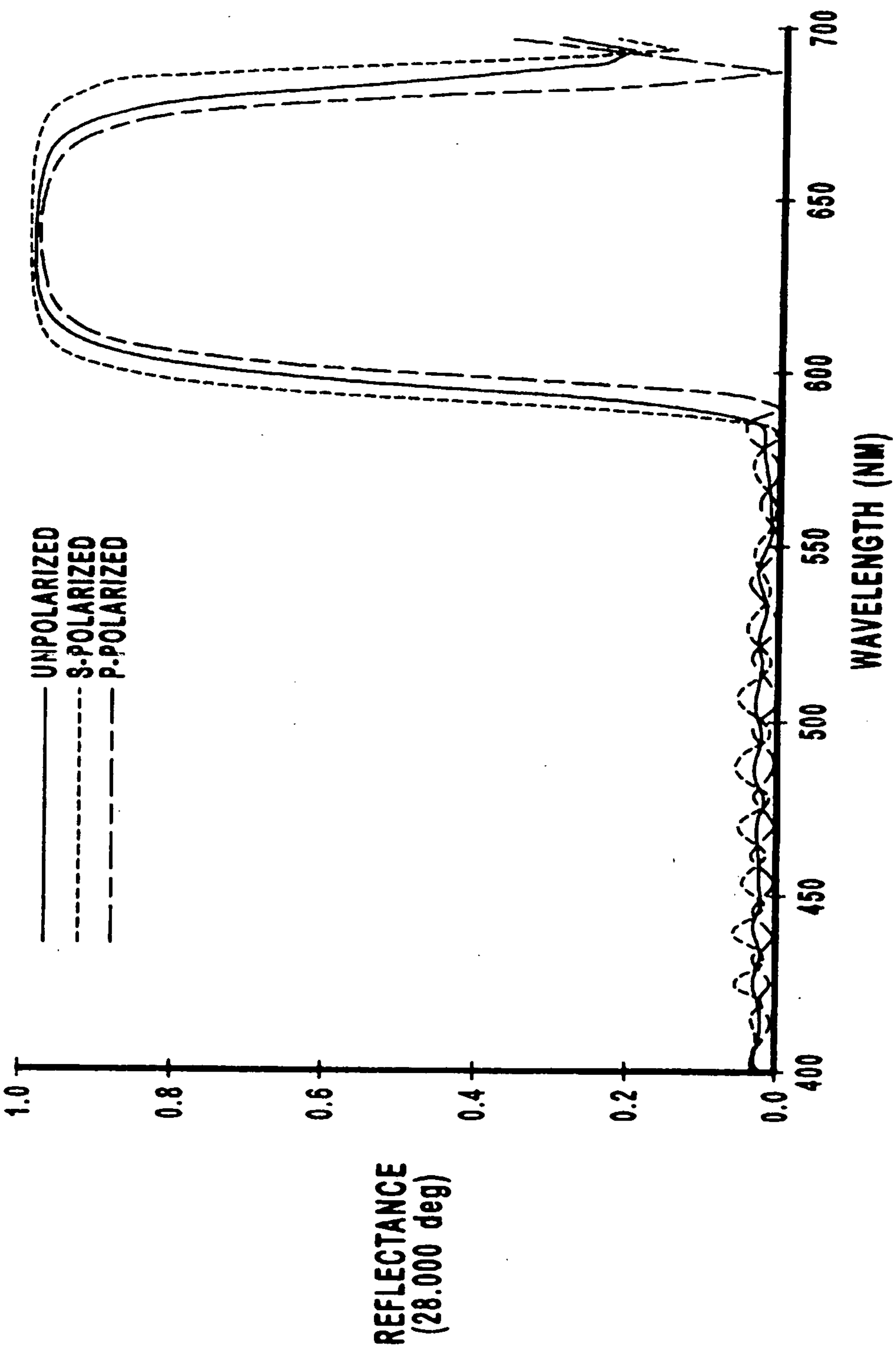

UNPOLARIZED
S-POLARIZED
P-POLARIZED
REFLECTANCE
(28.000 deg)
1.0
0.8
0.6
0.4
0.2
0.0
400
450
500
550
600
650
700
WAVELENGTH (NM)

FIG. 12

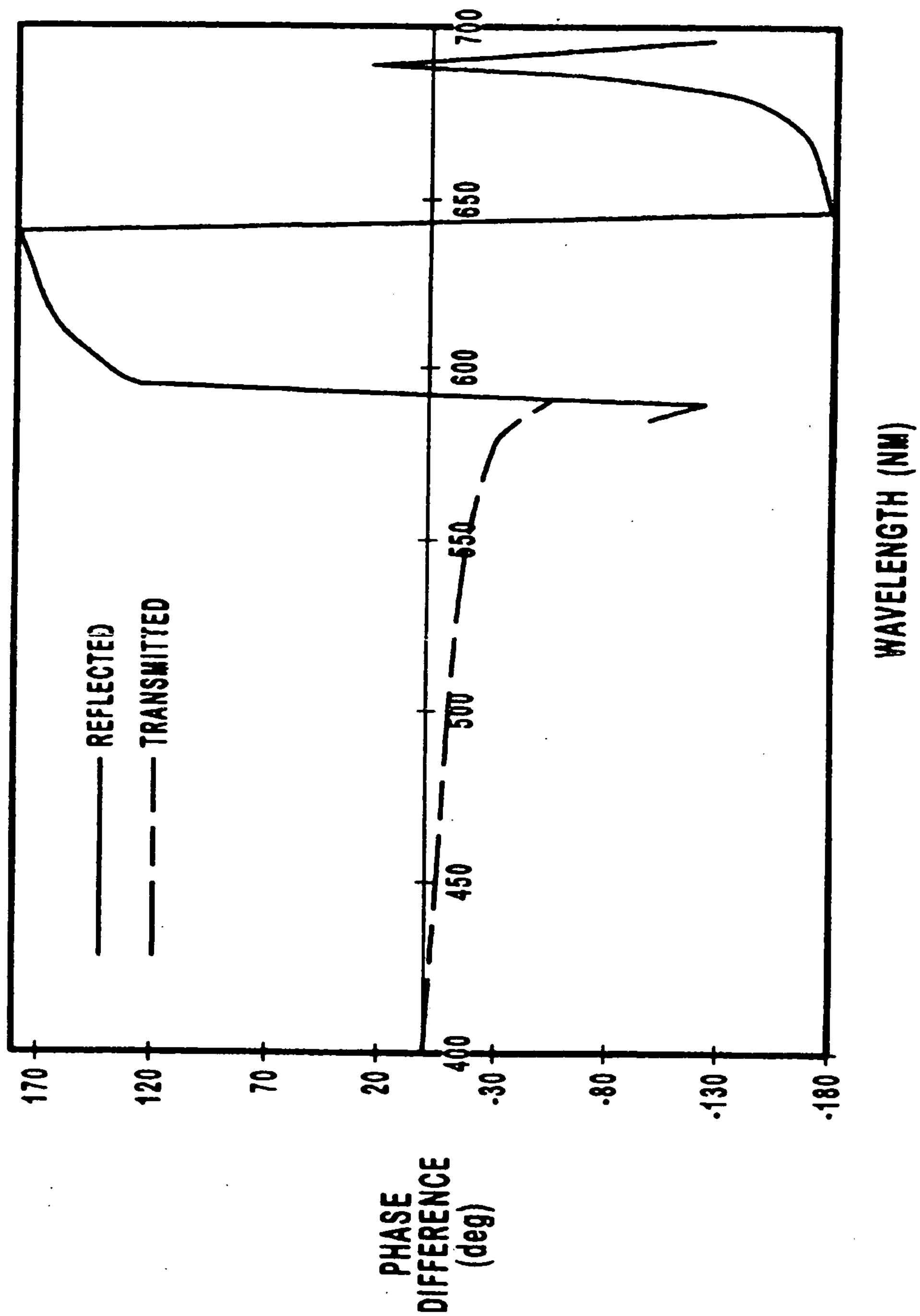

REFLECTED
TRANSMITTED
170
120
70
20
-30
-80
-130
-180
400
450
500
550
600
650
700
PHASE DIFFERENCE (deg)
WAVELENGTH (NM)

FIG. 13

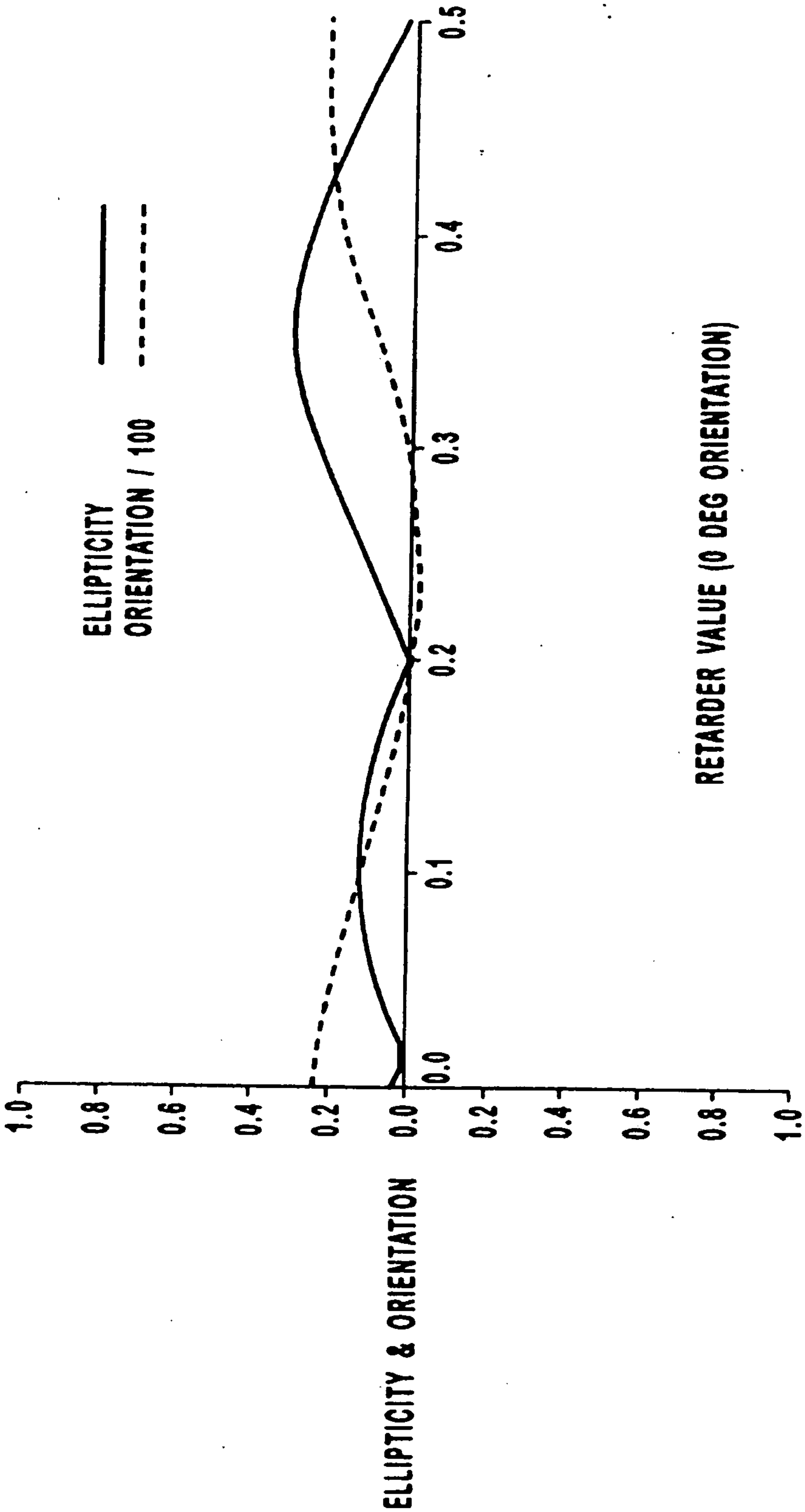

ELLIPTICITY
ORIENTATION / 100
RETARDER VALUE (0 DEG ORIENTATION)
0.0
0.1
0.2
0.3
0.4
0.5
ELLIPTICITY & ORIENTATION
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

FIG. 14

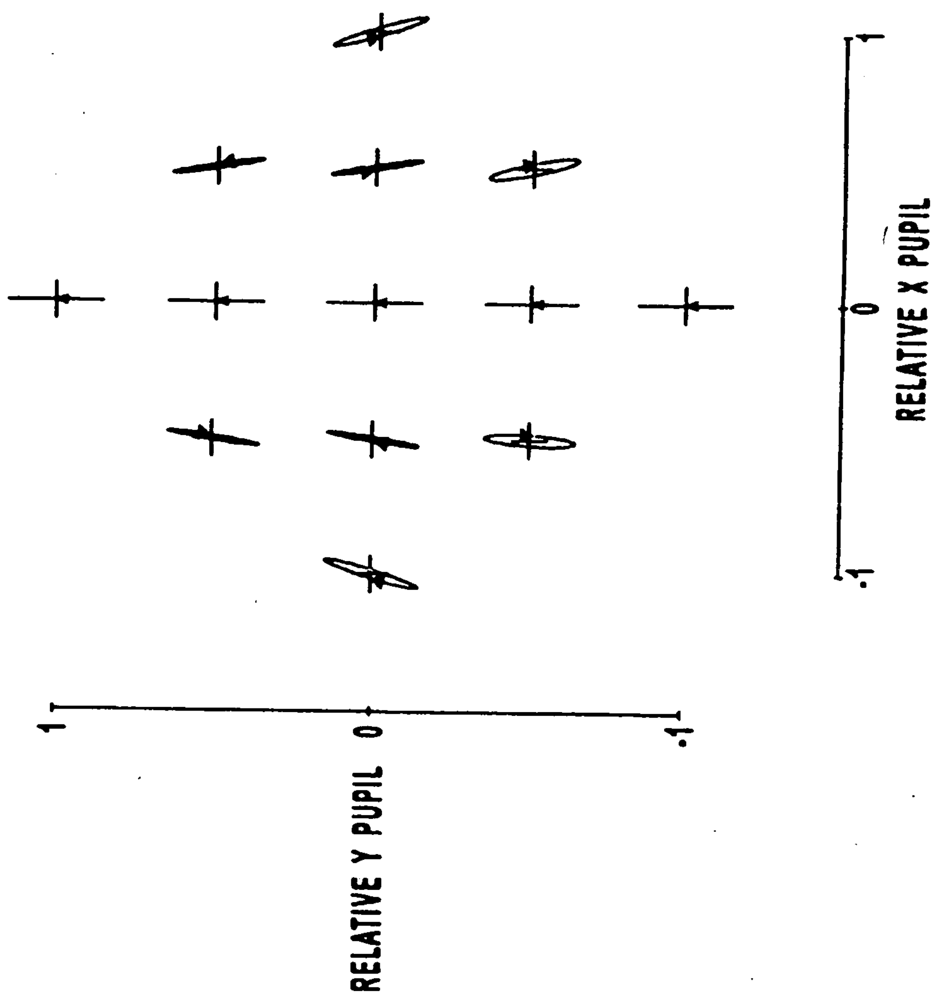


FIG. 15

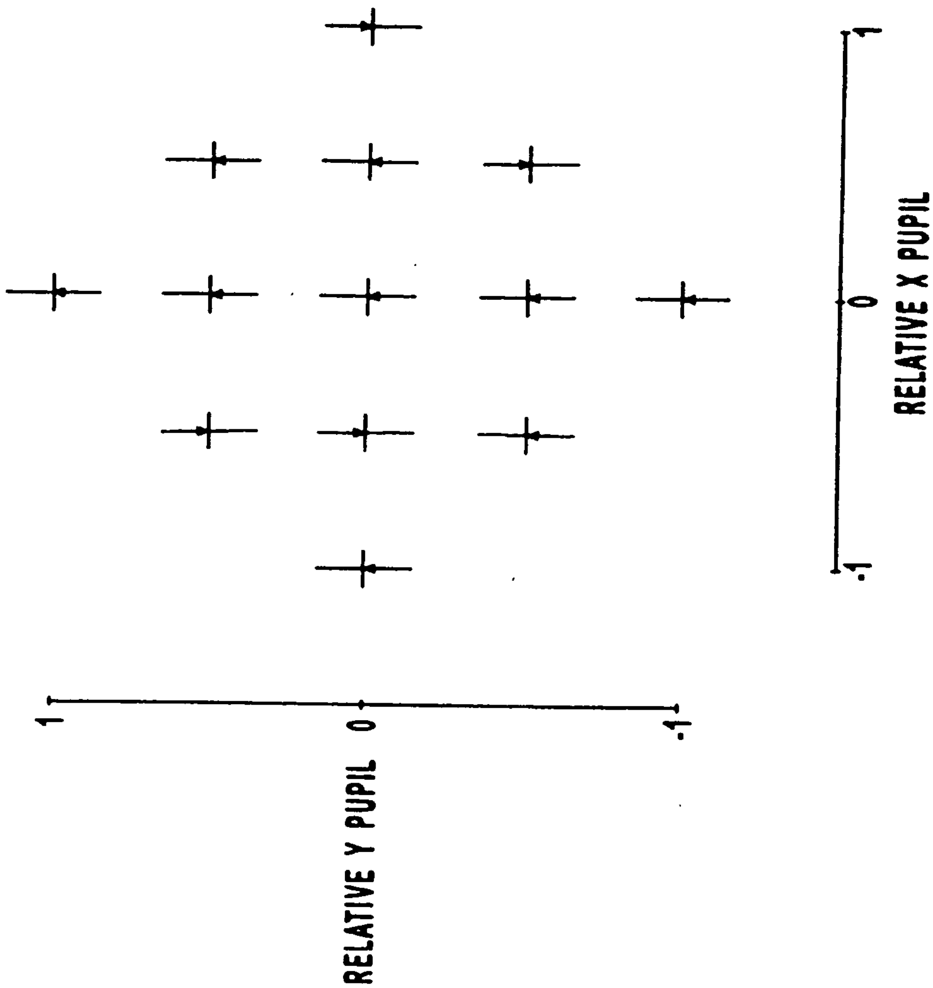


FIG. 16

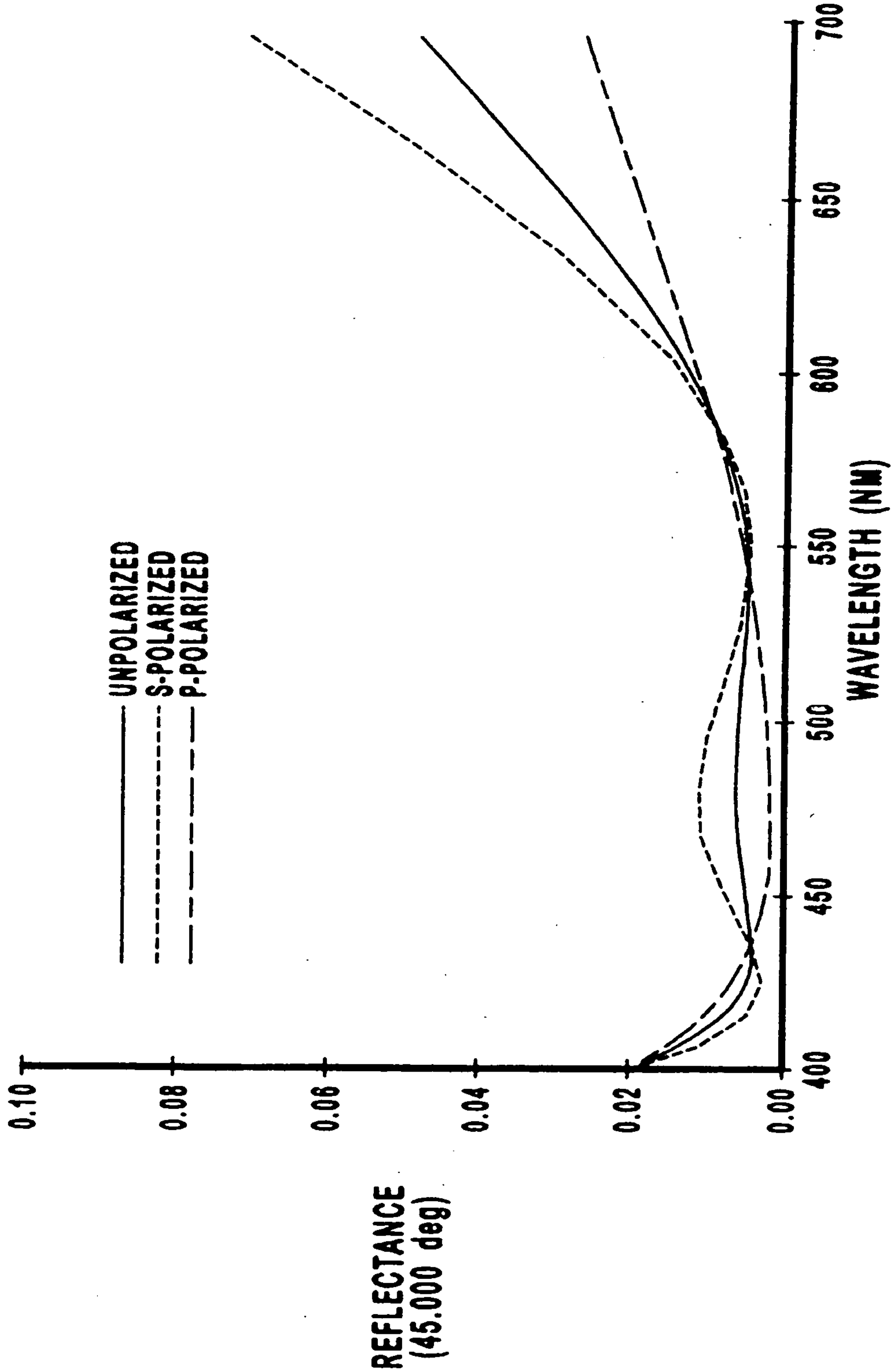

REFLECTANCE
(45.000 deg)
0.10
0.08
0.06
0.04
0.02
0.00
400
450
500
550
600
650
700
WAVELENGTH (NM)
UNPOLARIZED
S-POLARIZED
P-POLARIZED

FIG. 17

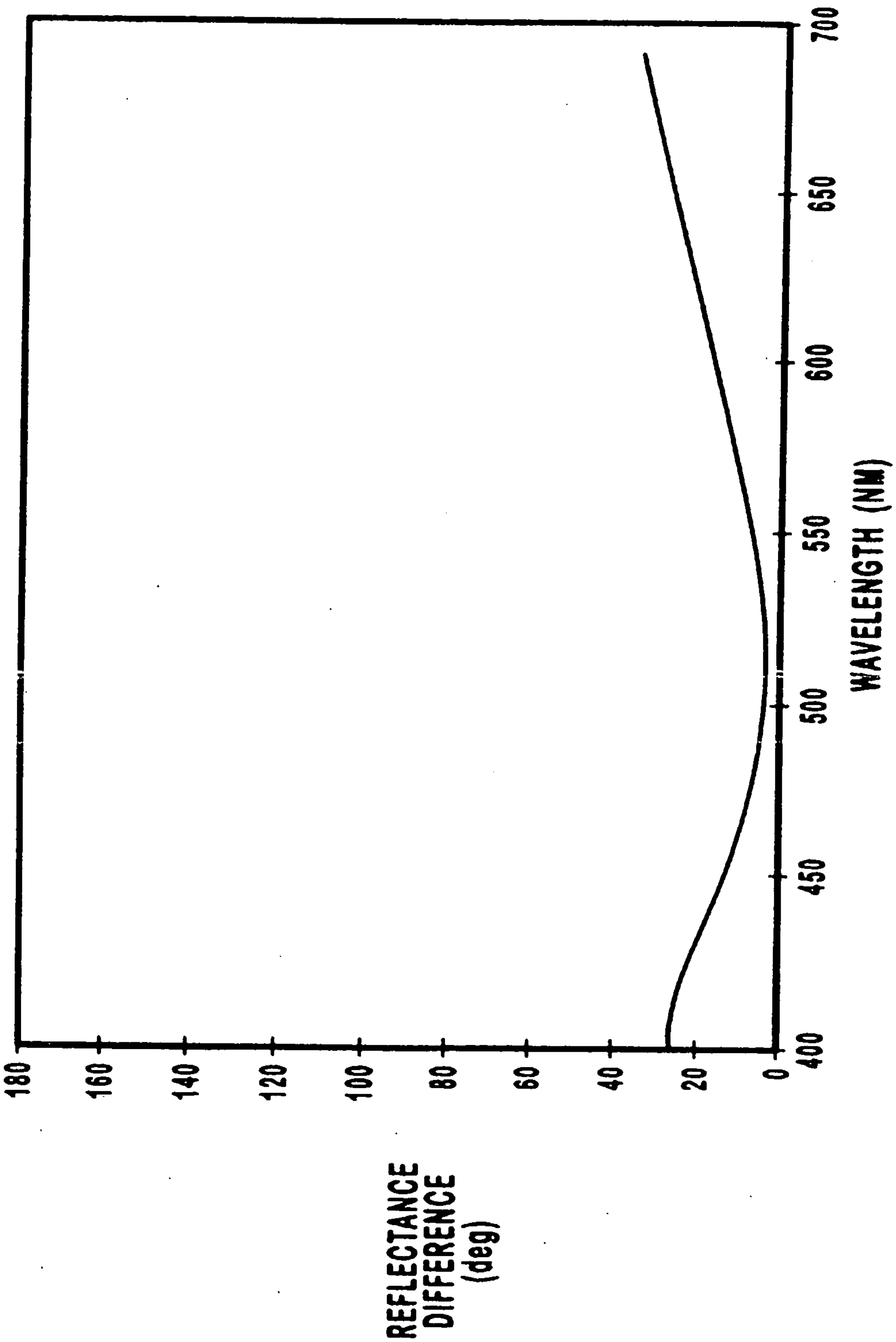
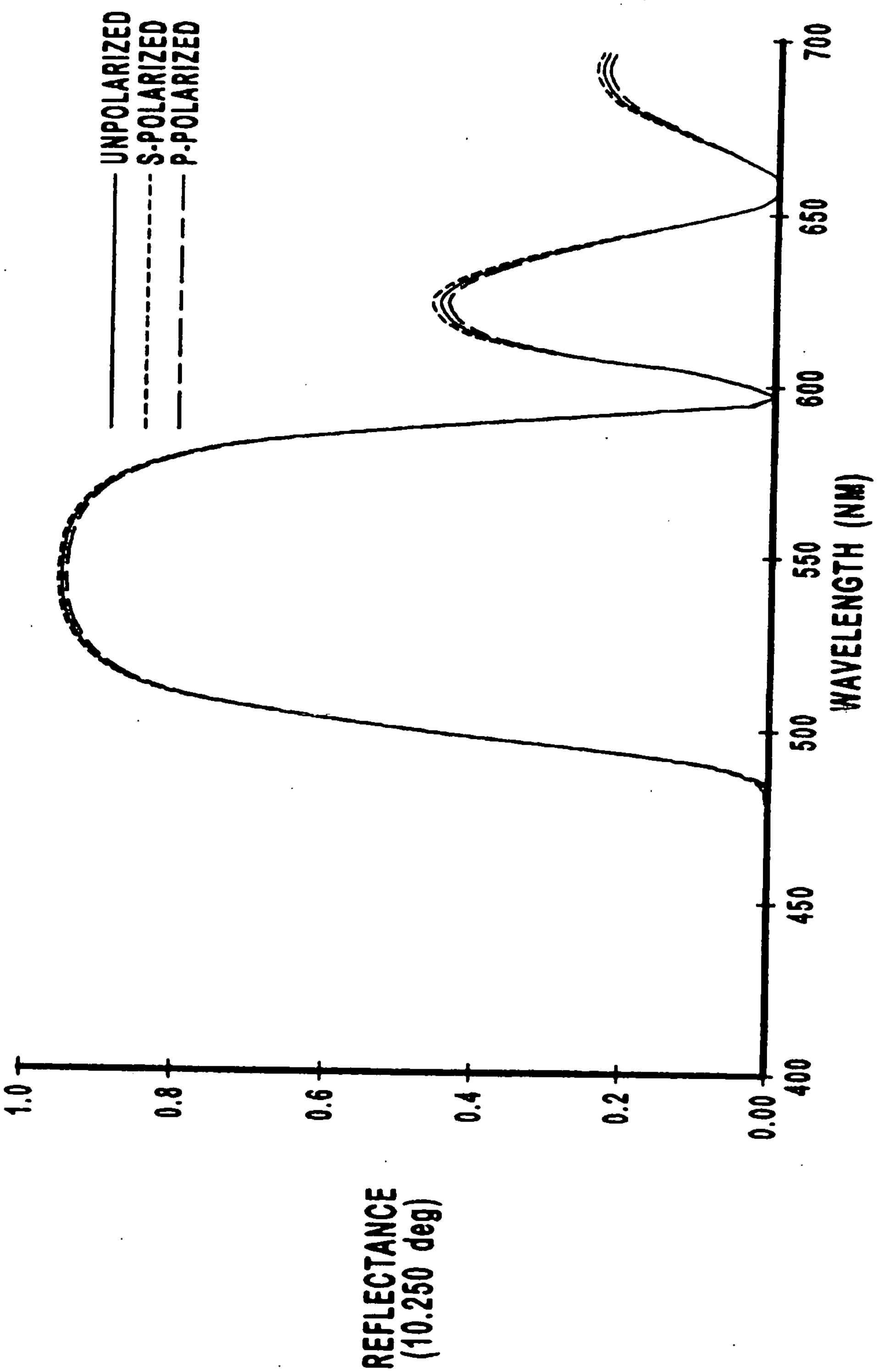

REFLECTANCE
DIFFERENCE
(deg)
180
160
140
120
100
80
60
40
20
0
400
450
500
550
600
650
700
WAVELENGTH (NM)

FIG. 18



UNPOLARIZED
S-POLARIZED
P-POLARIZED
REFLECTANCE
(10.250 deg)
1.0
0.8
0.6
0.4
0.2
0.00
400
450
500
550
600
650
700
WAVELENGTH (NM)

FIG. 19

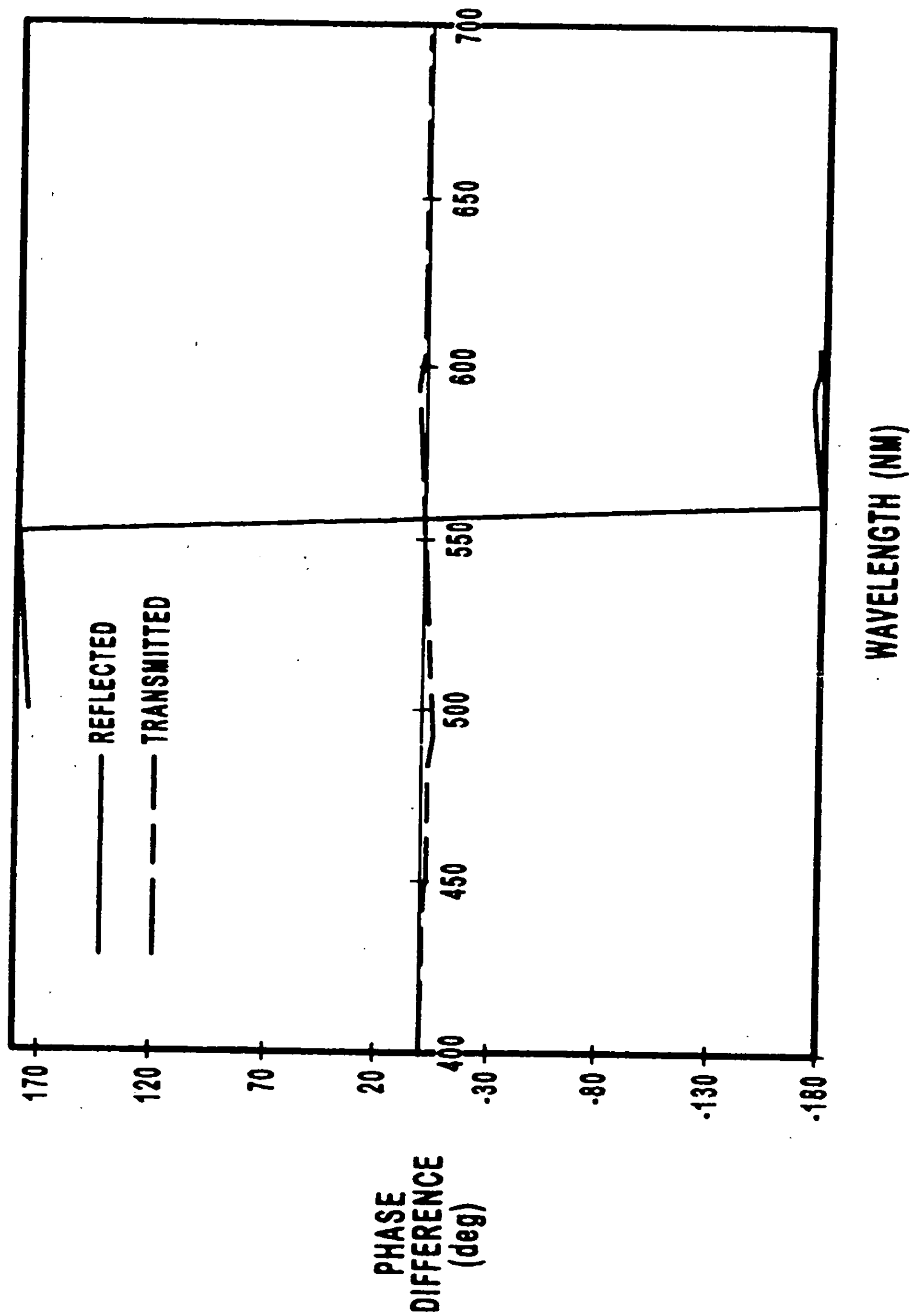

PHASE DIFFERENCE (deg)
170
120
70
20
-30
-80
-130
-180
WAVELENGTH (NM)
400
450
500
550
600
650
700
REFLECTED
TRANSMITTED

FIG. 20

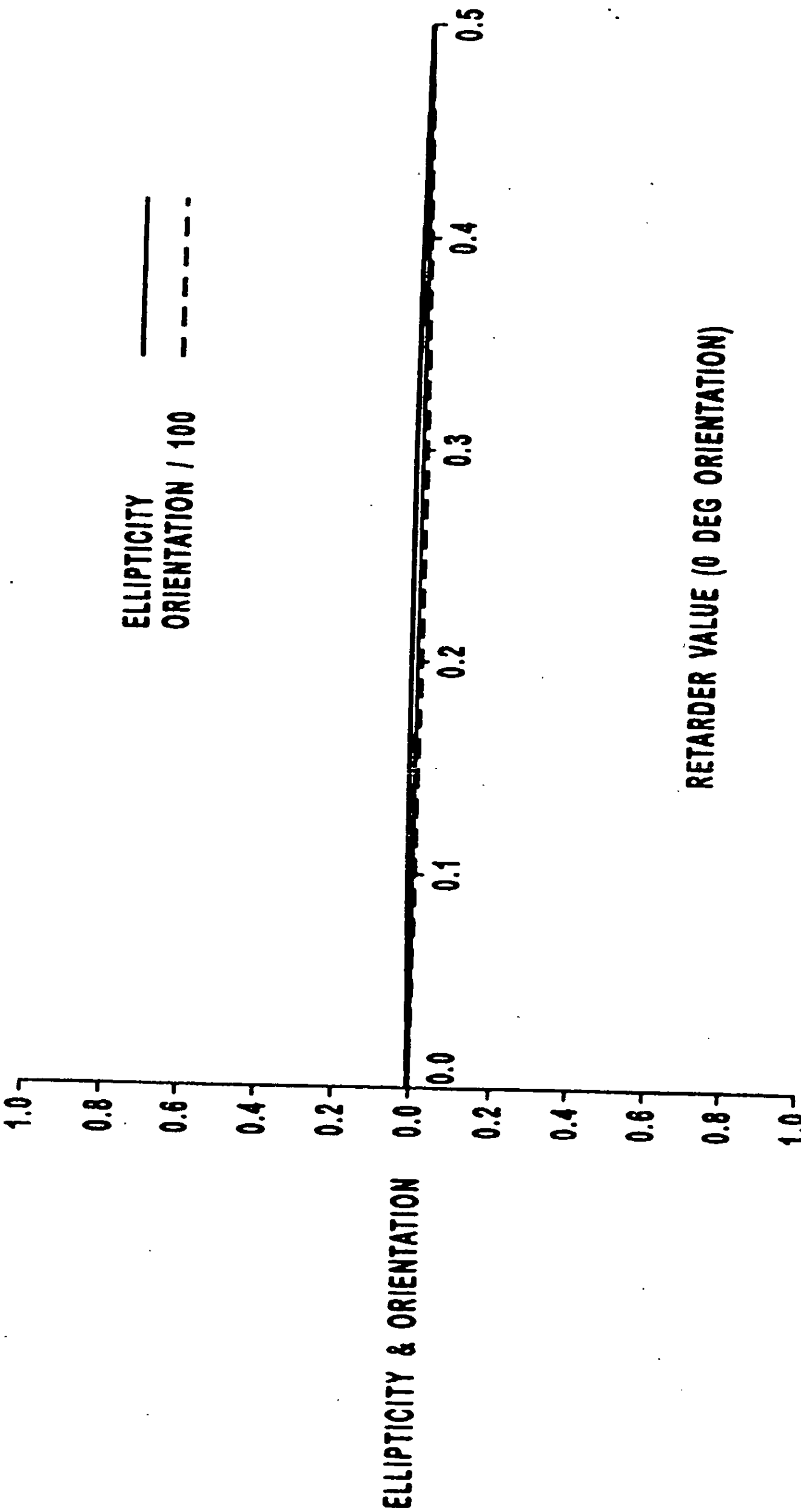

ELLIPTICITY
ORIENTATION / 100
RETARDER VALUE (0 DEG ORIENTATION)
ELLIPTICITY & ORIENTATION
0.0
0.1
0.2
0.3
0.4
0.5
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

FIG. 21

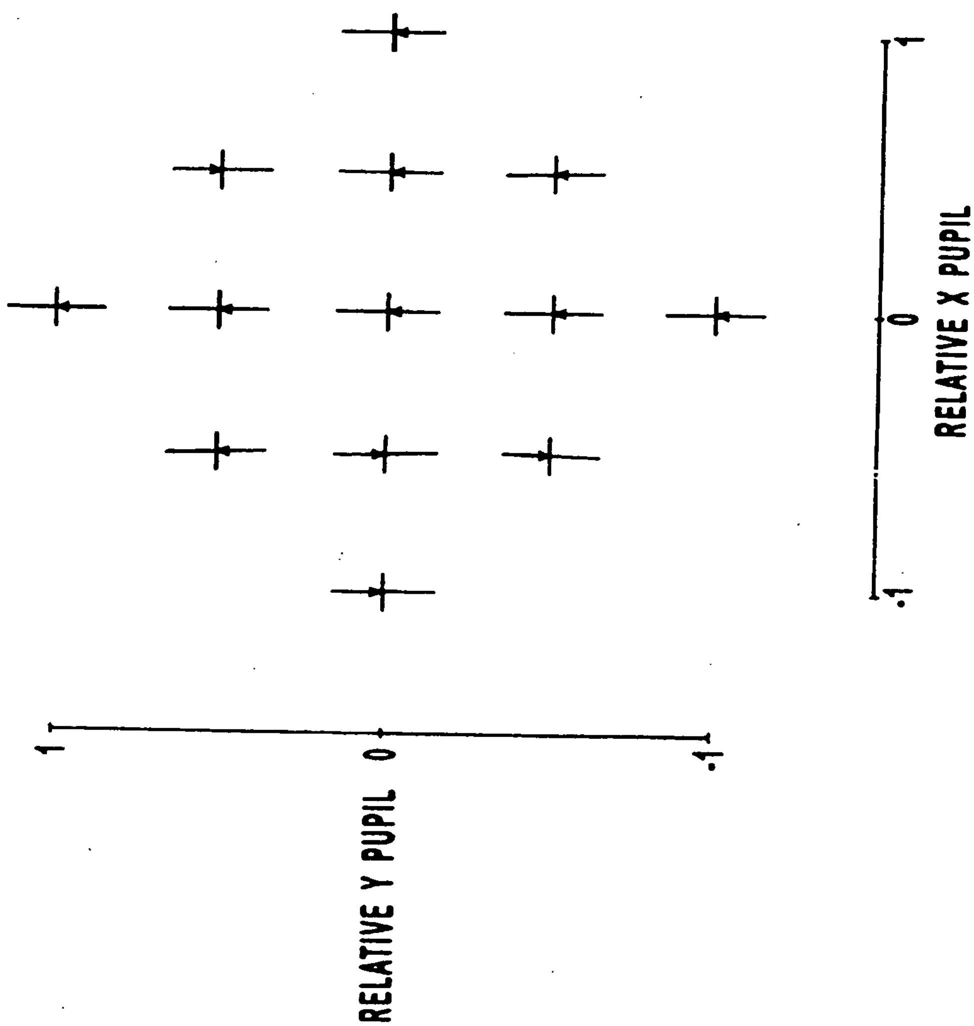


FIG. 22

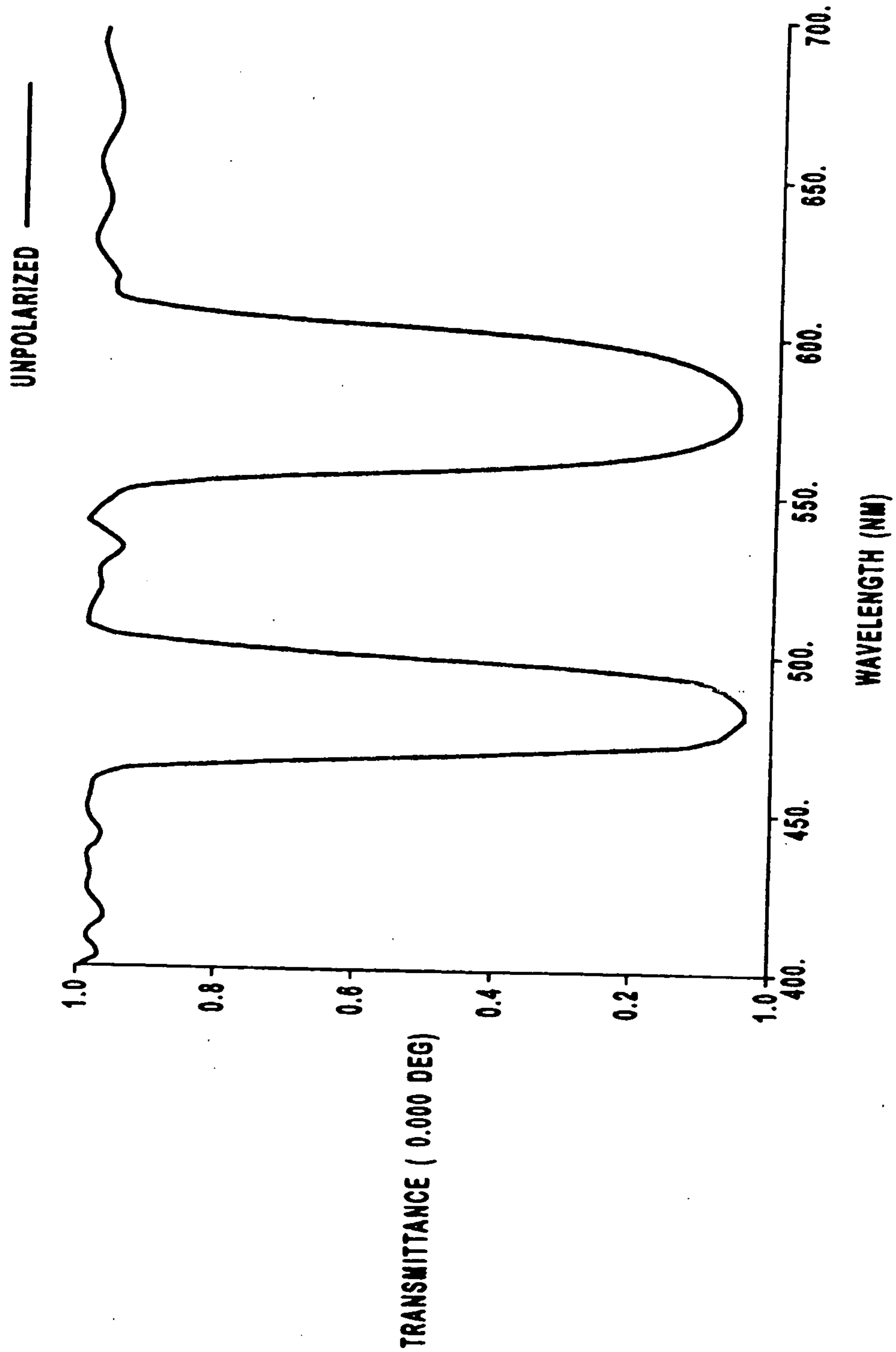

UNPOLARIZED
TRANSMITTANCE (0.000 DEG)
1.0
0.8
0.6
0.4
0.2
1.0
400.
450.
500.
550.
600.
650.
700.
WAVELENGTH (NM)

FIG. 23

SYSTEMS, METHODS AND APPARATUS FOR IMPROVING THE CONTRAST RATIO IN REFLECTIVE IMAGING SYSTEMS UTILIZING COLOR SPLITTERS

BACKGROUND OF THE INVENTION

1. The Field of the Invention

The present invention is directed to systems, methods and apparatus for achieving enhanced contrast in reflective imaging systems, such as those utilizing reflective liquid crystal display imagers and color splitting devices, such as Philips prisms. More particularly, the present invention is directed to systems, methods and apparatus for correcting undesired depolarization by color splitting devices. The invention maximizes the transmission of light polarized in a certain direction while minimizing the transmission of light polarized in another direction, thereby achieving a high contrast ratio which significantly improves the final image quality.

2. The Relevant Technology

Liquid crystal displays are commonly used in rear projection imaging systems. A reflecting type of liquid crystal panel comprises an array of pixels, which when activated works by reflecting incident light while simultaneously rotating the polarization vector of the light by 90°, typically when a voltage or signal is applied to an individual pixel. Thus the signal or image information is contained in the light which is of a particular polarization. If the liquid crystal imager is not activated, then those particular pixels of the liquid crystal imager are in the "off" state, and the light which is reflected from them will have no rotation of the polarization state. The signals from these "off" pixels should correspond to dark spots in the final image. One aspect of the quality of an image in such a system is measured through a parameter known as the contrast ratio, which is defined as the ratio of the light transmitted through the system in the on state divided by the amount of light transmitted in the "off" state. The higher the contrast ratio, the better the overall quality of the image. A display should project a bright image relative to the ambient lighting conditions. High brightness of the "on" pixels enhances the contrast ratio and allows the projector to be used in a broader range of ambient lighting conditions, i.e. a darkened room is not required.

Loss of contrast through a non-polarizing color splitting device such as a Philips prism results from a combination of the geometrical effect from skew rays as well as diattenuation and phase differences in the coatings of reflective and total internal reflection surfaces. The geometrical effects of a polarizing beam splitter have been described in detail in the Ootaki (U.S. Pat. No. 5,459,593) and Miyatake (U.S. Pat. No. 5,327,270), the disclosures of which are hereby incorporated by reference, as follows below. These geometrical effects are a pure rotation of the input linearly polarized light by a polarizing beam splitter. Rear projection imaging systems typically have a contrast ratios of not less than 50:1 as suggested in Ootaki, in the plots showing a 2% dark level (100%/2%=50:1. In the Ootaki patent, white light from a halide or xenon lamp is incident at an angle of approximately 45° onto a polarizing cubic beam splitter. The polarizing cubic beam splitter reflects light which is of s-polarization and transmits light which is of p-polarization (where s-polarization refers to light which has its polarization vector perpendicular to the direction of propagation, while p-polarization refers to light which has its polarization vector lying in the plane of propagation). The light which is of s-polarization is reflected by the polarizing beam splitter towards a dichroic mirror. The dichroic mirror in the Ootaki patent is designed in such a way as to reflect the s-polarized light which is of one color while transmitting the other color components of the beam. The use of more than one dichroic mirrors results in a separation of the incident white light into various color channels. In a typical imaging system, two dichroic mirrors are sufficient to separate incident white light into red, green, and blue color channels. The color selectivity of the dichroic mirror is achieved by the placement of specific optical coatings upon the mirror, which is a well known technique in the art for color separation.

In Ootaki, the first dichroic mirror is aligned in such a way as to reflect the light of one specific color towards a liquid crystal light valve, also commonly referred to as a "reflective imager". The other colors are then transmitted through the first dichroic mirror to other dichroic mirrors, which are coated to allow reflection of individual colors towards their respective liquid crystal light valve imagers. Each liquid crystal light valve has the property of reflecting incident light, which in this case consists of the s-polarized "read-out" light, along with the "writing" light from the "on" pixels which is inputted through the opposite side of the liquid crystal panel from a cathode ray tube. The light from the "on" pixels is of p-polarization. The synthesized image, which contains both the s-polarized light from the "off" pixels and the p-polarized "writing" light from each of the liquid crystal light valves passes back through the system and towards a polarizing prism of the cubic beam splitter type, which will only pass the p-polarized light directly through; and a final p-polarized image may be directed towards a screen through a projection lens.

A limitation in the quality of the performance of this system originates from the rotation of the plane of polarization in the polarizing prism for incident light rays which are not in an eigenstate. Since this rotation is independent of the state of the image generating pixels and causes leakage of light in the "off" state pixels the contrast is necessarily degraded.

Ootaki corrects for the geometrical effects of a polarizing beam splitter utilizing dielectric thin films on a tilted surface. In the color image display apparatus disclosed in Ootaki, each one of the 3 dichroic mirrors used for color separation at 45 degree incidence incorporate additional thin film layers to function as a compensating plate.

Miyatake discloses a similar approach to compensate for the polarizing beam splitter. The approach disclosed in the Miyatake patent is to compensate for the polarizing beam splitter with a quarter wave plate in the optical path between the reflecting type liquid crystal device and the polarizing prism. However this patent does not teach or consider phase differences that may occur in a color splitting device, such as a tilted dichroic mirror or a Philips prism. In the case of a Philips prism, phase differences occur from the reflection at the dichroic and total internal reflectance (TIR) surface. If the incident beam is convergent, so that the incident angle varies over the aperture of the beam, the modification of the polarization by each of these tilted surface is not uniform.

In U.S. Pat. No. 5,594,591 which issued to Yamamoto et al.; the disclosure of which is hereby incorporated by reference, the inventor has attempted to solve the same problem in a projection display wherein the color separation element is a Philips prism. This system is more compact than Ootaki's imaging system. A Philips prism is known in the art as a color separation device, to separate the polarized light into the three primary colors. The Philips prism disclosed in the Yamamoto et al. patent employs optical coatings upon

the faces of the Philips prism for color separation and an anti-reflection coating on the incident prism faces, which also form TIR surfaces. Yamamoto et al. also assert that the optical coatings on the TIR surfaces, which comprise alternating layers of SiO_2 and TiO_2, have a phase control function. The dichroic optical coatings used for color separation cooperate with the anti-reflection coating layers at the TIR surface in achieving this phase control function. While the dichroic coating designs and their spectral and phase characteristics are not shown, it is suggested that they have some phase control function; which combined with a 90 degree phase difference at the TIR surface corrects for the image degradation contributed by the polarizing beam splitter. The variation of polarization with incident angle is not necessarily corrected for in this manner, as this variation is strongly influenced by the angle dependent reflection and phase retardance properties of the dichroic coating.

Optical thin film coatings represent a significant cost component of color separation optics. The inventions taught in Ootaki and Yamamoto require extra thin film layers in these coatings to achieve the optimum compensating function to offset polarization effects that result from non-collimated light incident upon a polarizing beam splitter. Furthermore the phase control function of these layers adds complexity and cost to the coating manufacturing and control process. The thin film thickness must be controlled such that the proper phase function is obtained without degrading anti-reflection or color separation characteristics.

The polarization of light can also be modified with birefringent materials, i.e. a material whose refractive index varies as a function of direction. Birefringent materials are commonly used to form ¼ wave compensator or retardation plates. Quarter waveplates effectively introduce a relative phase shift of 90° in one of the polarization components of the incident beam as the light goes through the material one time, if the plate is oriented per perpendicular to the optical axis (the axis of the direction of propagation of the beam). A quarter waveplate has a thickness equal to an integer multiple of $\lambda/4$ (hence the origin of the term "quarter wave plate"), where λ is the wavelength of the light for a particular color channel. Accordingly, in a three color imaging system, there are three different waveplates each with different physical thicknesses calculated to be of a thickness appropriate for the wavelength of the particular channel.

Quarter waveplates can be formed from any of the typical birefringence optical materials. Typical birefringent optical materials include anisotropic crystals such as quartz, calcite, or mica, but may also be composed of organic materials having optical anisotropy. Optical anisotropy can be obtained by stretching sheets of polymeric materials to form films. Alternatively liquid crystal materials can be used as a variable compensating medium in the form of a liquid crystal cell wherein the orientation is modified by the application of electric field. Low molecular weight liquid crystals materials can be formed into solid materials having preferred orientation by the application electric field, or other orientation means, followed by the application of ultraviolet light to initiate a polymerization reaction. Additionally, high molecular weight polymers having liquid crystal properties are known and can be formed into compensating films or applied as discrete layers to substrates.

As previously indicated, conventional reflective imaging systems typically transmit light through a polarizing element, such as a polarizing beam splitter, which transmits or reflects a polarized component of the light, such as s-polarized light, to a color splitting device or color splitter, such as a Philips color splitting prism. Passing light through the TIR and dichroic interfaces of a Philips color splitting prism causes depolarization of the polarized light due to a combination of diattenuation, geometrical effects, and phase difference. While special coating designs can be used to make these phase differences offsetting, this is undesirable for practical manufacturing reasons. The use of conventional anti-reflection and dichroic coating designs in a color splitter changes the polarization state, thereby reducing image contrast and brightness. The phase change, or retardation, and intensity differences between polarization states transforms plane polarized light to elliptically polarized light. A polarizing beam splitter alone rotates the polarization vector of plane polarized light, which can be corrected with a quarter wave plate described by Ootaki. However, elliptical polarization is not corrected by the quarter wave plate. The combination of rotation and ellipticity of the polarization vector is the major source of light leakage when the reflective liquid crystal light valve is in the "off" state, decreasing the contrast ratio and brightness, thereby detracting from the image quality.

The key role of the quarter wave plate when used with a polarizing beam splitter, as taught by Miyatake, is to minimize the transmission of any off-axis polarization components due to geometrical effects in order to make the "off" state as dark as possible. The quarter wave plate can be oriented in such a way as to leave one of the linearly polarized light components, such as s-polarized light, unshifted, while effectively cancelling out unwanted p-polarized components for the "off" state of the reflective imager. When light is reflected from individual pixels of the liquid crystal light valve (LCLV) imager which are in the "off" state, the s-polarized component is again transmitted through the quarter wave plate unshifted. However, the unwanted p-polarized components will be shifted by another 90°, making a total shift of 180° with respect to its original direction, thereby cancelling out the unwanted components. Light reflected from the pixels of the LCLV which are in the "on" state will consist of p-polarized light. The p-polarized light reflected from the "on" state pixels will pass through the quarter wave plate only once and will accordingly be rotated only by 90°.

The image information from the LCLV travels back through the prism system to the polarizing beam splitter, which, as before, has the characteristic of reflecting s-polarized light while transmitting the final p-polarized image light towards the viewing screen. When utilizing a quarter wave plate in the optical path between each of the three liquid crystal light valves and the Philips prism in such a reflective imaging systems, the contrast ratio is improved by ensuring that the black level is closer to being completely black. While use of quarter wave plates in such a system proposes a means for the correction of rotations in the polarization vector due to the polarizing beam splitter, it does not address the undesired ellipticity and additional rotation added by the color splitter.

A quarter wave compensation plate is also used in U.S. Pat. No. 5,576,854 issued to Schmidt et al., the disclosure of which is hereby incorporated by reference. The Schmidt et al. patent was developed for monochromatic systems and does not address the issue of color imaging,. The system disclosed in Schmidt et al. works in a manner similar to the system disclosed in Miyatake, as previously described, namely by the reduction of off-axis depolarization induced by geometric effects when the light encounters the polarizing beam splitter. Schmidt et al. specifically mentions using a wave plate with a value of retardance equal to 0.25 to compensate for the off-axis polarization components gener-

ated by the polarizing beam splitter. However, Schmidt et al. additionally suggests that an additional retardance of 0.02 be included to compensate for the unwanted polarization shifts generated by the thermally induced birefringence of the LCLV, an effect which results in the dark state being lighter than desired. Accordingly, Schmidt et al. suggests that in monochromatic imaging systems the waveplate compensator have a total retardance value equal to 0.27 to compensate for the additional retardance, or phase delays between components due to the thermally induced birefringence in the LCLV.

It would be substantially beneficial to identify systems, methods and apparatus for improving the contrast in any imaging system using reflective liquid crystal light valves. More specifically, it would be a significant improvement in the art to minimize and correct for the rotations and ellipticity which occur in such systems that impair the contrast ratio by generating unwanted depolarization and contributing to light leakage in the "off" states of the image.

SUMMARY AND OBJECTS OF THE INVENTION

It is an object of the present invention to provide systems, methods and apparatus for improving the contrast ratio of a reflective imaging system which utilizes a color splitter which receives converging light from a polarized source impinging on a reflective imager, which then passes back through the color splitter whereby the polarizing source acts as an analyzer to emit a converging light cone toward a projection lens.

It is also an object of the present invention to provide systems, methods and apparatus for minimizing and correcting for the rotations and ellipticity which occur in such reflective imaging systems and impair the contrast ratio by generating unwanted components in the polarization, contributing to light leakage in the "off" states of the image.

It is a further object of the present invention to provide methods for separating the incident light into 3 colors with minimum loss of intensity at the desired wavelengths to form a color image of high brightness, while simultaneously achieving high contrast.

These and other objects and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

The present invention is directed to waveplate compensators having values which are uniquely optimized by identifying and minimizing particular polarization attributes. The waveplate compensators are utilized in reflective imaging systems wherein light is "double-passed" through the optical paths of the system. The optical paths can be summarized as follows: light passes through a polarizing beam splitter to polarize the light to a first polarization state and then enters a Philips prism. In the prism, the polarized light undergoes color-splitting through the use of dichroic and reflective coatings on selected surfaces. The separate colors are emitted from the prism assembly to reflective imagers or liquid crystal light valves, which change the polarizing state of the reflected light in accord with a desired image. The reflected light is passed, once again, through the prism assembly where the separate colors are converged and the diverging light is emitted to a projection lens for display of the image on a screen.

Color splitters which utilize optical interference coatings at oblique incidence, such as a Philips prism, typically exhibit a phase difference between the polarization states as well as diattenuation. This introduces rotation and ellipticity into the polarization state. The image brightness of the "on" state pixels is reduced while the brightness of the "off" state pixels is increased since the polarizing element is less effective as an analyzer in transmitting signals to the projection lens. The contrast ratio is determined by dividing the transmitted light having the selected polarization state, which corresponds to the "on" pixels of the liquid crystal light valve, by the amount of light transmitted which is in other states of polarization. This contrast ratio of the light from a reflective imaging system is a measure of the purity of the polarization state of the transmitted light. The higher the contrast ratio, the better the overall quality of the image.

The contrast ratio of a reflective imaging system is enhanced by the use of the inventive waveplate compensator positioned to intercept light being transmitted from the color splitter to the reflective imager and light being reflected from the reflective imager to be inputted for the second time into the color splitter. The waveplate compensator retardation value is selected with reference to minimizing particular polarization attributes.

The optimum contrast ratio is achievable if the retardance of the waveplate, being a function of the material and optical thickness of the waveplate, is calculated in such a way as to compensate and cancel out the unwanted polarization components for the "off" state of the image, thereby making the dark state close to completely black. This enhances the final image quality through a substantially improved contrast ratio. The optimum retardation is characterized by both the ellipticity and the ellipse orientation, or rotation of the polarized incident light, being sufficiently minimized for the entire cone angle of the illumination system or pupil.

The desired retardation is identified by calculating the ellipticity and orientation of the polarization vector at the edge of the pupil and then locating the retardation values at which both the ellipticity and orientation are simultaneously at a minimum. The ellipticity and elliptical polarization orientation are identified by: determining the pupil size of a cone of light as the light is incident in an image projection system at a location intended for placement of a waveplate compensator; determining the path of a ray, preferably a marginal ray; calculating the Stokes parameters; and then calculating both the ellipticity and elliptical polarization orientation of light at retardance value intervals. Preferably, progressively smaller iterations in the retardation are then made to optimize the contrast and brightness. The waveplate is oriented such that the maximum brightness is transmitted for pixels in the "on" state (i.e. the fast or slow axis is oriented at zero degrees with respect to the input polarization).

Display quality is enhanced when the intensity of each color channel is maximized in proper balance to insure accurate color rendition and purity with respect to a standardized display format, such as NTSC or PAL. In a double pass color separation imaging system the intensity for each color channel is maximized by 1) obtaining the maximum integrated throughput from the light source, or lamp, over the wavelength range which defines each color channel, 2) overlapping the entire spectral response over the wavelength range of the color channel for the s—polarized and p—polarized light, 3) matching the correction efficiency of the compensating plate over the entire wavelength range of the color channel, and 4) utilizing anti-reflection coatings on entrant, and preferably emergent, faces of polarizing and/or color separation optical elements having immersed dichroic or polarizing interference filters.

The goal of maximizing the brightness presents severe thin film design constraints. The aforementioned spectral

characteristics cannot be changed independently of each other, nor can they be changed without affecting the rotational and elliptical distortion of the polarized light. Thin film interference filters that are used to reduce reflection and achieve color separation, dichroic mirrors, have angle dependent performance and must be optimized over the cone angle of the incident light. When light is incidence at oblique incidence on these coatings the s and p planes of polarization of the reflected light undergo changes in phase, δ. It is the objective of this invention to provide dichroic mirrors having efficient color separation and saturation whereby the undesirable polarization effects are completely corrected for by a combination of correcting optical elements. Specifically the dichroic filter performance is optimized so that any residual leakage which cannot be corrected for by the compensating plate is removed by an auxiliary filter element without compromising the brightness of each color channel, thereby maintaining their balance color fidelity.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the manner in which the above-recited and other advantages and objects of the invention are obtained, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 depicts a schematic representation of a reflective imaging system utilizing the inventive waveplate compensators.

FIG. 2 is a schematic perspective view of a simple BK7 prism depicting a pupil and a marginal ray traced for ellipticity and orientation calculation.

FIG. 3 is a schematic side view of the simple BK7 prism shown in FIG. 2 depicting a pupil and a marginal ray traced for ellipticity and orientation calculation.

FIG. 4 is a polarization pupil map which relates to the light path shown in FIGS. 2–3 and which graphically shows the resulting ellipticity and orientation change due to the total internal reflection surface.

FIG. 5 illustrates the phase difference, in degrees, vs. angle, in degrees, for total internal reflection in a substrate having a 1.52 index for fraction.

FIG. 6 is a pupil map of the polarization state for a polarizing element tilted at 45° with respect to the optic axis for a cone angle equal to F/2.8, which is equivalent to 10° in air.

FIG. 7 is a plot of the ellipticity and orientation of the polarization vector at the marginal ray location for a waveplate compensator having retardance values ranging from 0 to 0.5 at an orientation of 0° with respect to the input polarization state. More particularly, FIG. 7 plots the relevant values as the red light passes through the first triangular prism R of the Philips prism shown in FIG. 1, liquid crystal light valve 90 and waveplate compensator 80 located therebetween, which has incrementally varied retardation values.

FIG. 8 relates to FIG. 7 and is a pupil map of the polarization state through the first channel, the red light channel, without a compensator plate.

FIG. 9 relates to FIG. 7 and is a pupil map of the polarization state through the red light channel, with a compensator plate having a retardance value of 0.20.

FIG. 10 illustrates the calculated reflectance for unpolarized, s-polarized and p-polarized light at normal incidence of the anti-reflection coatings on surface **41a** of prism R in FIG. 1, from 400 nm to 700 nm.

FIG. 11 compares the phase difference, in degrees, between s-polarization and p-polarization states in reflection for the anti-reflection coating on surface **41a** for prism R at the total internal reflection angle.

FIG. 12 illustrates the reflectance of the first triangular prism R in FIG. 1 located on surface **41b** for wavelengths of light from 400 nm to 700 nm, thus including the visible region. The reflectance of unpolarized, s-polarized and p-polarized light are shown as separate curves for an angle of incidence of 28°.

FIG. 13 illustrates the phase difference, in degrees, between s-polarization and p-polarization states for reflected and transmitted light for the dichroic coating on surface **41b** of prism R in FIG. 1.

FIG. 14 is a plot of the ellipticity and orientation of the polarization vector at the marginal ray location for a waveplate compensation having retardance values ranging from 0 to 0.5 at an orientation of 0° with respect to the input polarization state. More particularly, FIG. 14 plots the relevant values as the green light passes through the second triangular prism G of the Philips prism as in FIG. 1, liquid crystal light valve 110 and waveplate compensator 100 located therebetween, which has incrementally varied retardation values.

FIG. 15 relates to FIG. 14 and is a pupil map of the polarization state through the second channel, the green light channel, without a compensator plate.

FIG. 16 relates to FIG. 14 and is a pupil map of the polarization state through the green light channel, with a compensator plate having a retardance value of 0.20.

FIG. 17 illustrates the calculated reflectance for unpolarized, s-polarized and p-polarized light at 45° angle of incidence of the anti-reflection coatings on surface **51a** of prism G in FIG. 1, from 400 nm to 700 nm.

FIG. 18 compares the phase difference, in degrees, between s-polarization and p-polarization states in reflection for the anti-reflection coatings on surface **51a** for prism G at the total internal reflection angle.

FIG. 19 illustrates the reflectance of the second triangular prism G in FIG. 1 located on surface **51b** for wavelengths of light from 400 nm to 700 nm, thus including the visible region. The reflectance of unpolarized, s-polarized and p-polarized light are shown as separate curves for an angle of incidence of 10.25°.

FIG. 20 illustrates the phase difference, in degrees, between s-polarization and p-polarization states for reflected and transmitted light for the dichroic coating on surface **51a** of prism G in FIG. 1.

FIG. 21 is a plot of the ellipticity and orientation of the polarization vector at the marginal ray location for a waveplate compensator having retardance values ranging from 0 to 0.5 at an orientation of 0° with respect to the input polarization state. More specifically, FIG. 21 plots the relevant values as the blue light passes through the quadrangular prism B of the Philips prism shown in FIG. 1, liquid crystal light valve 130 and waveplate compensator 120 located therebetween, which has incrementally varied retardation values.

FIG. 22 relates to FIG. 21 and is a pupil map of the polarization state through the third channel, the blue light channel, without a compensator plate.

FIG. 23 illustrates the spectral performance characteristics of the notch filter as the calculated transmittance at normal incidence for unpolarized light from 400 nm to 700 nm.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed to systems, methods and apparatus for improving the contrast ratio of a reflective imaging system which utilizes a color splitter. More particularly, the present invention is directed to methods and apparatus for correcting undesired depolarization of color splitters through the use of uniquely designed waveplate compensators. The waveplate compensator maximizes the transmission of light polarized in the "on state" while minimizing the transmission of light polarized in the "off state", thereby achieving a high contrast ratio which significantly improves the final image quality.

Light entering a reflective imaging system of the present invention passes through a polarizing device such as a polarizing beam splitter which delivers polarized light, such as s-polarized light, to a color splitter. The color splitter, such as a Philips prism, separates the polarized component of light into the three primary colors. S-polarized blue light, s-polarized green light and s-polarized red light exit the color splitter at three separate locations and are output to three reflective imagers, such as liquid crystal light valves. Each reflective imager modulates the polarization state of each of the three primary color lights and reflects the modulated light back into the color separation device in accord with a desired image such that the light is "double-passed" through the color splitter. Accordingly, if a polarized component of light, such as s-polarized light, initially enters a color splitter, the light is returned to the color splitter in the "on state" as three primary color lights which are p-polarized. The color splitter then outputs a divergent cone of p-polarized light which passes through the polarizing element and may then be directed towards a screen through a projection lens.

Conventional color splitters virtually always introduce some depolarization into the transmitted light due to geometrical and thin film coating effects. When transmitted by the color splitter, this portion of the light has polarization properties different than the desired polarization state and, thus, the presence of this light decreases the contrast ratio of the reflective imaging system. As previously indicated, the contrast ratio is determined by dividing the transmitted light having the selected polarization state, which corresponds to the "on" state of the liquid crystal light valve, by the amount of light transmitted which is in other state of polarization, corresponding to the "off" state. Additionally, as previously discussed, the contrast ratio of the light from a reflective imaging system is a measure of the purity of the polarization state of the transmitted light. The higher the contrast ratio, the better the overall quality of the image.

In accord with the systems, methods and apparatus of the present invention, the contrast ratio of a reflective imaging system is enhanced with a waveplate compensator positioned to intercept light being transmitted from the color splitter to the reflective imager and light being reflected from the reflective imager to be inputted for the second time into the color splitter. The waveplate compensator is formed from a material and has thickness which are selected with reference to minimizing particular polarization attributes. The details related to the waveplate compensator are set forth hereinbelow after an exemplary embodiment of a reflecting imaging system of the present invention is described.

FIG. 1 depicts an exemplary embodiment of the present invention which improves the contrast ratio of a Philips prism assembly used in a reflective LCD rear projection system. Although the embodiment shown in FIG. 1 is presented in the context of a reflective LCD system using a Philips prism, it will be appreciated that this is an example which is illustrative and not limiting.

The system shown in FIG. 1 receives input illumination from a light source 10, which may typically be white light from a source such as a xenon, metal halide or tungsten lamp. Light source 10 is an example of a light source means for providing light. The light from light source 10 is incident upon a polarizing beamsplitter 20. The light preferably passes through a color tuning filter or a notch filter 12, which is described in greater detail hereinbelow, before being directed to polarizing beam splitter 20.

As shown, the light is preferably directed to the polarizing beam splitter 20 as convergent light and then to a Philips type of prism assembly 30. It is also possible to have a light source directing light to a polarizing beam splitter as a collimated beam which then passes through a convergent lens (not shown) located between polarizing beam splitter 20 and Philips prism 30. Such a lens is an example of convergent lens means for converging light. The benefits of the present invention are, however, particularly appreciated when convergent light is utilized. The present invention corrects for both rotation and ellipticity which result when convergent light is used while collimated light generally introduces only rotation.

Polarizing beam splitter 20 is an example of a polarizer or a polarizing means for polarizing light such that a first polarized component of light in a first polarization state is transmitted. Another example of a suitable polarizing means is a polarizing cubic beam splitter. Polarizing beam splitter 20 transmits light of one type of polarization (either s- or p-polarized light; for the purpose of example, let the light in this case be of p-polarization), while reflecting light of the other type of polarization (s-polarized in this example) into a direction 90° with respect to the direction of incidence. S-polarized light refers to light which has its polarization vector perpendicular to the plane of incidence; whereas p-polarized light refers to light which has its polarization vector lying in the plane of incidence.

The s-polarized light is reflected into Philips prism 30. The Philips prism assembly is an example of a color splitter or color splitting means for separating a first polarized component of light into three primary color lights. Other examples of color splitting means include beamsplitter cubes, X-prisms, L-prisms and flat, tilted plate dichroic mirrors. Persons of skill in the art will appreciate, however, that the methods and apparatus of the present invention can also be applied to color splitters having residual phase difference and diattenuation, such as a color splitter utilizing antireflection or dichroic coatings having a non-zero but uniform phase difference across the spectral region of interest. Since other color splitters are also suitable for achieving the separation of the incident white light into separate color channels, the Philips prism should not be construed as limiting.

Philips prism 30 comprises a first triangular prism R, a second triangular prism G and third quadrangular prism B. Each prism is preferably formed from solid glass. Philips prism 30 is configured as a conventional Philips prism to orient the red, green and blue light channels respectively through prisms R, G and B. However, the Philips prism may utilize less conventional dichroic coating configurations

such that the red, green and blue light channels are not respectively directed through prisms R, G and B.

Light enters into first triangular prism R, preferably at normal incidence, through incident surface **41***a*. Incident surface **41***a* is coated with a standard type of antireflection coating **42**. The incident beam travels through the prism R until it encounters splitting surface **41***b*, which is coated with a dichroic coating **44**. Dichroic coating **44** is designed to have particular spectral response and phase characteristics to act in cooperation with the other elements of the invention, which will be further described below.

These types of dichroic coatings are known in the art, and serve the purpose of reflecting light of one predetermined wavelength or color (red, for example) while transmitting light of all other colors (green and blue, for example). If the dichroic coating **44** on reflecting surface **41***b* is made such that it reflects red light, then the red light will be reflected at an angle towards incident surface **41***a*. The red light undergoes total internal reflection at surface **41***a* after which it passes out of prism R through exit surface **41***c*, which is coated with an antireflection coating **46** on the exterior surface. The light then enters waveplate compensator **80**, also known as a retarder. The dichroic coating generally has a nonzero phase retardance and a substantially constant phase retardance for the wavelength of light encountering the dichroic coating.

Second triangular prism G has an incident surface **51***a*, a reflecting surface **51***b* and an exit surface **51***c*. Incident surface **51***a* of second triangular prism G is disposed adjacent reflecting surface **41***b* of first triangular prism R and is air spaced from this surface. The green and blue light transmitted through surface **41***b* and dichroic coating **44** passes through a small air space and then enters second triangular prism through incident surface **51***a*. Incident surface **51***a* is coated with an antireflection coating **52**. A dichroic coating **54** is formed on reflecting surface **51***b* for reflecting the green component of the light and for transmitting the blue component of the light. The reflected green light is then directed to **51***a* where it undergoes total internal reflection and then passes out of prism G through surface **51***c* which is coated with an anti-reflection coating **56**. The light then enters into a waveplate compensator **100**.

The third quadrangular prism B has an incident surface **61***a* and an exit surface **61***c*. The incident surface **61***a* is mounted on reflecting surface **51***b* of second triangular prism G so that the blue component of light transmitted through dichroic coating **54** enters third quadrangular prism B through incident surface **61***a* and then exits via surface **61***c* which is coated with an anti-reflection coating **66**. The light then enters into a waveplate compensator **120**.

Any conventional infrared blocking coatings, anti-reflection coatings, dichroic coatings, color tuning filters coating may be utilized with the present invention, such as the coatings specified hereinabove as being located on the Philips prism. Examples of suitable infrared blocking coatings, anti-reflection coatings, dichroic coatings, color tug filters and other desirable coatings which may be utilized in the system, are set forth in detail in *Optical Thin Films User's Handbook* (1987) by James D. Rancourt, and Design of Optical Interference Coatings (1989) by Alfred Thelen, which is hereby incorporated by reference. The preferred dichroic coatings are set forth in copending U.S. patent application Ser. No. 09/079,997 entitled Thin Film Dichroic Color Separation Filters for Color Splitters in Liquid Crystal Displays and filed by Stephen D. Browning, Paul M. LeFebvre and Basil Swaby concurrently herewith; the disclosure of which is hereby incorporated by reference.

As there are typically three color channels, namely red, green, and blue, there could be three separate waveplate compensators **80**, **100** and **120**. However, waveplate compensator **120** is unnecessary in the preferred embodiment so there are only two waveplate compensators. Each waveplate compensator is in a light or optical path between the respective exit locations or exit surfaces **40***c*, **50***c* and **60***c* and the respective liquid crystal light valves **90**, **110** and **130**, such that there are three complete color channels. The waveplates may be attached or bonded directly onto either the color splitting means, such as Philips prism **30** or the reflective imager such as **90** or **110**, may be free standing between the reflective imager and the color splitting prism, or may be buried in a prism component.

Each of the three colored cones of light is incident upon its respective reflective imager **90**, **110** and **130** and the light from the liquid crystal light valves will be reflected back through the waveplate compensators **80**, **100** and **120** and will contain the optical signal information which will form the final image for viewing upon a screen **150**. Some of the pixels of the reflective imager or imaging liquid crystal light valves may be on and some off, in accordance with the image. Light which is reflected from the pixels which are on will have their polarization shifted by 90° by the liquid crystal light valves or LCLV, while light reflected from the pixels in the "off" state will not experience any change in polarization state due to the LCLV. Such liquid crystal light valves are examples of reflective imagers or reflective imager means for modulating a polarization state for each of the three primary color lights and for reflecting or redirecting the red light, the green light and the blue light thus modulated back into the color splitting means.

After reflected light from the pixels of each LCLV in the "off" state traverses back, the light passes through the corresponding waveplate compensators **90**, **110**, and **130** which are designed to effectively compensate for any rotations and ellipticity in the polarization vector. Accordingly, the contrast ratio in these liquid crystal imaging systems is enhanced by reducing the light leakage in the "off" states of the image into the "on" state. Contrast ratios on the order of 500:1 or greater can be achieved with the present invention.

The optical paths of "double-passing" the light in the system shown in FIG. 1 can be summarized as follows: light passes through a polarizing beam splitter **20** to polarize the light to a first polarization state and then enters the prism assembly **30**. In prism **30**, the polarized light undergoes color-splitting through the use of dichroic and antireflective coatings on selected surfaces. The separate colors are emitted from the prism assembly to reflective imagers **90**, **110**, and **130** which change the polarizing state of the reflected light in accord with a desired image. The reflected light is passed, once again, through prism assembly **30** where the separate colors are converged and the divergent light is emitted to a projection lens **140** for display of the image on a screen **150**. Any conventional projection lens may be utilized. Such lenses are examples of projection lens means for projecting an image onto a screen.

Previous systems have utilized a quarter wave plate at the image to correct for the rotation introduced by a polarizing beam splitter. However, quarter wave plates are particularly inadequate in reflective imaging systems utilizing color splitters such as a Philips Is prism which is non-polarizing, have multiple dielectric surfaces and have a total internal reflection surface. The polarization in such complicated systems cannot be corrected simply with a quarter wave plate as the polarization is not simply rotated. The polarization vectors can be shifted, or rotated, off axis each time the

light goes through the multiple layers of the dichroic coatings and as a result suffer from phase lags between the components of the beam as they progress through the optical media, which yield a degree of off axis components in the polarization. Such a complicated color splitting arrangement transmits light with a residual ellipticity and off-axis rotations of the polarization planes which yields unacceptable contrast without some mechanism such as the inventive waveplate compensators.

Accordingly, the waveplate compensators are necessary to adjust for nonuniform changes in the light as the light is incident upon the many reflective and transmissive surfaces in the imaging system. The inventive waveplate compensator effectively reduces unwanted polarized light entering the prism assembly for the second pass-through and thereby increases the polarization purity of the light that is emitted from the prism assembly to the projection lens. The value of the waveplate compensator is selected to effect a predetermined phase difference to retard, and thereby substantially eliminate, that portion of the inputted light from the reflective imager that is incident at an angle to the plane of polarization of the color splitter, i.e., light that is not in an eigenstate of the plane of polarization of the color splitter. In this manner, the portion of light inputted from the reflective imager that undergoes depolarization is substantially reduced such that the contrast ratio of the reflective imaging system is greatly increased and the outputted convergent cone of light is substantially entirely composed of light having the selected polarization state and a high-contrast projection image is achieved.

Stated otherwise, since certain optical elements such as polarizing beam splitter **20** directionally modify the skew rays comprising a first polarized component of light, it is necessary for the waveplate compensator to then modify the polarization state of the skew rays passing therethrough. As a result of utilizing such a waveplate compensator, a second component of light having a second polarization state enters into Philips prism **30** with each skew ray having a second polarization vector substantially orthogonal to the first polarization vector of the respective skew ray.

The waveplate compensators are composed of a birefringent material, usually an anisotropic crystal such as quartz, calcite, or mica; however, certain types of organic polymeric plastics which have different indices of refraction for different crystallographic axes are also suitable.

A preferred form of a waveplate compensating material is stretched organic polymer film due to its low-cost and ease of obtaining the film with different retardation values. However, such films typically have a surface that is largely unsuitable in this application since it results in image distortion unless the resulting compensator is attached to the color splitting means, such as the exit surfaces of the prism, and is also substantially separated from the image plane.

The waveplate compensator may also be liquid crystal materials in the form of a typical liquid crystal or LCD cell. Additionally, a liquid crystal material can be transformed into a solid after the appropriate molecular orientation has been achieved. This can be done with a polymer having liquid crystal side chains or photopolymerizable liquid crystal molecules.

The LCD cell is contained between two opposing surfaces such as two opposing plates. Additionally, the two opposing surfaces may also be a single plate opposite a surface of the color splitting means, such as exit surfaces **41***c* of prism **30**, or a single plate opposite a surface of the imager means, such as the surface of imager **90** opposite exit surface **41***c*.

The waveplate compensator is preferably oriented at 0° and the fast axis of the waveplate compensator is preferably oriented parallel to the desired input polarization state from the reflective imager. More specifically, each waveplate compensator is oriented in such a manner that when the light is, for example s-polarized, the s-polarized component remains unshifted while other components are shifted by a specific amount in one pass. The change in shift is determined through the equation $\Delta\phi=2\pi\,\Delta n(d/\lambda)$; where $\Delta\phi$ is the phase shift incurred in one pass through the waveplate compensator, Δn is the difference in the refractive indices of the two optical axes of the waveplate and is characteristic of its birefingence, d is the physical thickness of the waveplate, and λ is the wavelength of the light.

The present invention suggests that optimum contrast ratio is achievable if the retardance of a waveplate is selected such that the unwanted polarization components for the "off" state of the image are substantially eliminated or diminished. As a result, the dark state is close to completely black which substantially improves the contrast ratio, thereby enhancing the final image quality.

Such benefits are achieved by retarding light by a wave value at which both the ellipticity and the elliptical polarization orientation of the light are approximately at a minimum. The value at which both the ellipticity and the elliptical polarization orientation of the light are approximately at a minimum is referred to herein as the polarization rotation elimination retardance value. After the polarization rotation elimination retardance value is identified then a waveplate compensator can be obtained which has a retardance selected to retard light by a wave value which corresponds with the polarization rotation elimination retardance value. Selecting the retardance of the waveplate compensator involves selecting a birefringent material and then identifying the thickness necessary to yield the desired retardance.

One method of identifying a wave value at which both the ellipticity and orientation are simultaneously at a minimum involves calculating the ellipticity and orientation of the polarization vector at the edge of the pupil. The calculations are based on the principle that the ellipticity and orientation can only be corrected "perfectly" at one point in the pupil or incident ray angle. The pupil is a two dimensional cross-section, the two dimensions being the spatial coordinates of the plane perpendicular to the direction of propagation of the beam, of a cone of light. The invention utilizes the extreme pupil ray, sometimes referred to as the marginal ray. The marginal ray refers to the ray traced from the source point to the edge of the pupil at its widest point. A marginal ray is shown at **220** in FIG. 2 and FIG. 4. FIGS. 2–4, which are based on a simple total internal reflection prism, are discussed in Example 1 in greater detail.

The marginal ray **220** or pupil point is used for the calculations. It should be understood that other rays within the pupil may also be used depending on other conditions such as pupil uniformity. FIG. 4 which is also discussed in Example 1 graphically shows the resulting ellipticity and orientation change for a single TIR surface. The calculations are also based on mathematical descriptions of polarized light. For example, the possible states of polarized light can be represented by a set of four intensity quantities known as Stokes parameters. The four Stokes intensity parameters are designated by S_0, S_1, S_2, S_3. Operationally, the term S_0 represents the total intensity, S_1 represents the intensity through a horizontal linear polarizer, S_2, represents the intensity through a 45° linear polarizer, and represents the intensity through a right circular polarizer. The Stokes

representation is thoroughly described in "Ellipsometry and Polarized Light" by Azzam, which is hereby incorporated by reference.

Polarized light may be conveniently described by resolving the components of the electric field vector into an x and a y component, z being the direction of propagation of the light beam. Rotation can be parameterized in terms of an angle in the x-y plane by which the polarization vector is rotated from its initial orientation after light passes through some medium or undergoes reflection at an interface. The orientation of the polarization vector after it passes through a system can be calculated by following, the rotations of the electric field vector through this system.

In conventional notation a perfectly monochromatic electric field vector is comprised of two orthogonal vibrations independent of time with a form

$$E = \begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} |E_x|e^{i\delta_x} \\ |E_y|e^{i\delta_y} \end{bmatrix}$$

where $|E_x|$ and $|E_y|$ are the electric field amplitudes and δ_x and δ_y are the phase components of the wave. Using this definition, the Stokes parameters or vectors can be recast as:

$$S_0 = E_x^2 + E_y^2$$

$$S_1 = E_x^2 - E_y^2$$

$$S_2 = 2E_xE_y \cos\Delta$$

$$S_3 = 2E_xE_y \sin\Delta$$

where $\Delta = \delta_y - \delta_x$ and is commonly known as the phase difference. With this formulation, a ray can be traced through an optical system containing thin film coatings, total internal reflection surfaces, and polarization components using standard techniques as referenced herein or with commercially available software. To find the ellipticity and orientation of the resulting polarization ellipse given the Stokes vector at the output of the system, the following equations are defined:

$$\text{Orientation} = \alpha = \tfrac{1}{2}\arctan(S_2/S_1)$$

$$\text{Ellipticity} = e = \tan[\tfrac{1}{2}\arcsin\{S_3/((S_1)^2+(S_2)^2+(S_3)^2)^{1/2}\}]$$

After understanding that the orientation of the polarization vector is described through an angle α and that the ellipticity is expressed through the parameter e, then α and e are calculated with a retarder orientated at 0° with respect to the input polarization in double pass through the prism. The retarder value is varied between 0 and 0.5 wave and a null configuration for both orientation and ellipticity is located to determine the optimum value of the compensator.

These calculations can be done by hand, or alternatively, one may input the parameters in the above equation into a suitable computer program since such calculations can be tedious for systems that contain up to hundreds of layers of optical materials of varying composition. In addition to four Stokes intensity parameters, there are other methods of mathematically describing polarized light which can be utilized to calculate and describe ellipticity and orientation. These include but are not limited to the Jones vector and coherency matrix representations. Software programs such as "Code V", which is produced by Optical Research Associates of Pasadena, Calif., and is utilized for optical ray tracing using the Jones calculus to propagate the light through the system and to then calculate the Stokes vector from this information.

The ray tracing programs perform the aforementioned calculations for every interface in the optical system for each of the user defined rays. The intensity and polarization of each ray is calculated sequentially as it is modified by each interface and material through which it traverses in the calculated optical path. Additional details on these procedures and algorithms can be found in the operation manual for "CODE V" dated August 1997, for version 8.20, which is hereby incorporated by reference. The ray tracing program is used in this invention to calculate the phase retardance in transmission and reflection at each interface as well as the intensity, in reflection and transmission for each polarization direction. The rotation, ellipticity and intensity in the "on" and "off" states are calculated for a plurality of skew rays which represent the marginal rays, at the periphery of illumination cone, and rays having various intermediate angles between chief ray and marginal rays.

Repeated calculations are then made with the ray tracing program to optimize to display brightness and contrast. The first step is to construct an analytical model of the optical system. Thin film designs for the anti-reflection and dichroic coating can be optimized using a commercially available thin film design program, examples of which are "TFCALC", commercially available from Software Spectra Inc. of Portland, Oreg. As shown in FIG. 4, a plurality of skew rays, preferably twelve skew rays, including the marginal rays which have the maximum angle of incidence as defined by the optical systems f#, are used in this simulation along with the chief ray, which is parallel to the optic axis. When the thin film coating designs are specified for each surface (along with the refractive index of the thin film materials and the other optical elements and the polarizing characteristics of the liquid crystal light valve in the "on" and "off" states) the ray tracing program can calculate and display the ellipticity and rotation for all the specified rays.

Optimum values of thickness of the waveplate can range anywhere from 0 to half of wavelength or λ/2 and will vary from system to system. After the ellipticity and orientation have been calculated for intervals of a wavelength, it is preferable to graph the calculated values of the ellipticity and rotation of the polarization for a particular system as a function of retardance. Examples of such graphs are shown in FIGS. 7, 14 and 21. The value where the ellipticity and rotation both intersect the abscissa, in other words, when both are simultaneously equal to zero, then the corresponding value of retardance on the abscissa is the optimum value of the waveplate for a particular imaging system.

The waveplate value is separately calculated for each color channel as each color channel could require a different waveplate. Specific examples of identifying the ellipticity and orientation minimums for separate channels are provided by Examples 2–4 which correspond with FIGS. 5–12.

The optimized retardation value for a compensating plate is found in two stages. In the first stage a marginal ray is corrected to remove rotation and ellipticity. This is done by modeling an additional compensating element in the ray tracing program having a variable retardance. The retardance is set at finite values from 0 to 0.5. By plotting the rotation and ellipticity for the marginal ray for each of these finite retardance values it is possible to identify a first local minima wherein both the ellipticity and rotation are close to zero.

The object of the simulation is to optimize the contrast and brightness of the display. In this second stage of optimization, the relative intensity of the all the rays are calculated and summed to give an integrated intensity over the cone angle, which will be proportional to the observed

brightness of the actual image in the "on" state. The contrast is determined as set forth hereinbelow.

Brightness=Σ of the intensity of each ray in the "on" state across the applicable wavelength range.

After making the identical calculation for the "off" state, the contrast may calculated as:

Contrast=Σ of the intensity of each ray in the "on" state/Σ of the intensity of the ray in the "off" state

Another method of identifying the optimum retardance value of the waveplate is to plot measured or experimentally determined values of the ellipticity and rotation of the polarization for a particular system as a function of retardance. This can be accomplished by measuring the Stokes parameters with techniques known to those skilled in the art. While it is possible to obtain the data required to calculate the ellipticity and orientation experimentally, it is preferable to obtain the data through calculations.

The waveplate compensators disclosed herein are examples of waveplate compensator means for retarding at least one of the three primary color beams to achieve a predetermined phase difference.

As mentioned hereinabove, it is preferable to direct the light through a color tuning filter or a notch filter as shown in FIG. 1 at 12. Notch filters are especially useful in the first color channel, such as the red color channel, described in conjunction with first triangular prism R as the reflection angles within the prism are relatively extreme. Such notch filters are examples of notch filter means for tuning the wavelength ranges of light transmitted by the polarizing means to the color splitting means. More specifically, the notch filter means reflects incidental light such that the light entering the color splitting means has selected wavelength ranges.

EXAMPLES OF THE PREFERRED EMBODIMENTS

Examples are provided of the present invention in order to provide specific models for identifying the optimal wave retarder material and thickness in accordance with the present invention. Examples 1 and 2 do not involve the use of a waveplate compensator but are included to provide examples of rotation and ellipticity. Examples 3A–3D are all related to a projection system as shown in FIG. 1. Examples 3A–3C set forth the properties of each respective color channel. Example 3D details a notch filter as shown in FIG. 1 at 12 which is used in the system detailed in Examples 3A–3C.

Example 1

FIG. 2 is a schematic perspective view and FIG. 3 is a schematic side view of a simple BK7 prism used as an example to determine the orientation and ellipticity in accordance with the methodology described hereinabove with reference to the Stokes parameters. FIGS. 2 and 3 depict a total internal reflection prism at **200** and a pupil at **210**. A marginal ray traced for ellipticity and orientation calculation is shown at **220**. The chief ray is shown at **230**. It should be understood that other rays within the pupil may also be used depending on other conditions such as pupil uniformity.

The calculations were based on an incident converging light entering the prism with a 10° cone angle (F/# 2.88), striking a total internal reflection surface tilted to 56°, and then exiting the prism at exit surface **202**. It was assumed that the prism surfaces had no coatings, so the transmission losses were due to Fresnel reflection losses at the input and output faces. FIG. 5 depicts the variation in phase difference vs. the angle at which total reflection occurs, for a substrate having a refractive index of 1.52. While rays parallel to the optic axis undergo reflection at 56° resulting in a phase difference of approximately 30°, the phase difference of skew rays in the y-z plane will vary from 28° to about 32°. The s-polarization and the p-polarization vectors for skew rays lying in the x-z plane differ from the respective s-polarization and p-polarization vectors for the chief ray and rays lying within the y-z plane. The phase difference on reflection at the TIR surfaces in FIG. 3 will be compounded for the rays in the x-z plane according to FIG. 5, resulting in a net change in the polarization state varying with the angle between the skew rays and the z axis, of the optic axis. The greatest change occurs for a marginal ray at the edge of the pupil in the x-z plane.

Tracing a marginal ray at the edge of the pupil as shown in FIG. 2, the Stokes parameters can be calculated as provided hereinbelow in Table 1.

TABLE 1

	ST_0	ST_1	ST_2	ST_3
Input Polarization	1.00000	−1.00000	0.00000	0.00000
Prism Entrance	0.95536	−0.95536	0.00000	0.00000
TIR Surface	0.95536	−0.77473	−0.55402	−0.07460
Prism Exit	0.91278	−0.87294	−0.25702	−0.07140
Image	0.91278	−0.87294	−0.25702	−0.07140

Using these parameters in the ellipticity and orientation equations as set forth above based on the Stokes parameters yields an orientation of 8.203° and an ellipticity of −0.039. A polarization pupil map is shown in FIG. 4 which graphically shows the resulting ellipticity and orientation change of the total internal reflection surface. The polarization vector for skew rays which have a relative x axis pupil displacement of zero is not modified, while the maximum polarization vector rotation and ellipticity occurs for skew rays on the relative y axis pupil equals zero, when the relative x-axis pupil is −1 or 1.

Example 2

FIG. 6 provides an example wherein the prism in example 1 is replaced by a polarizing element tilted at 45° in the optical system having an illumination cone angle equal to an f# of 2.8, which is equivalent to 10° air. The polarizing element does not comprise any interference coatings. Thus, it can be seen that a polarizing element, such as is disclosed in U.S. Pat. No. 5,549,593 issued to Ootaki, only causes rotation, and not ellipticity.

Overview of Examples 3A–3D

Examples 3A–3D are all related to a projection system as shown in FIG. 1. Although, Examples 3A–3D all relate to a single exemplary system, each example highlights the characteristics of separate portions of the system.

The benefits of utilizing a reflective imaging system as shown in FIG. 1 with a waveplate compensator of the present invention and the same system without a waveplate compensator are compared in Examples 3A–3C. Each of the color channels, red, green and blue, are separately described respectively in Examples 3A–3C. Example 3A describes the properties of the red color channel of the system with reference to FIGS. 7–13. Example 3B sets forth the properties of the green color channel with reference to FIGS. 14–20. FIGS. 21–22 relate to the blue color channel described in Example 3C. Example 3D details a notch filter

or color tuning filter as shown in FIG. 1 at 12 which is used in the system detailed in Examples 3A–3C. Example 3D described the notch filter with reference to FIG. 23.

The rotation and ellipticity which results in each color channel are shown before a waveplate compensator is used. The results are then compared when a waveplate compensator is utilized which has been designed to have an optimal retardance.

Examples 3A and 3B detail the optical properties of the thin film materials, the thickness of the thin film layers and the order of deposition of each antireflection coating and dichroic coating respectively located on Prism R and Prism G of the Philips prism depicted in FIG. 1. The sequence and thickness of the deposited materials are provided in Tables 2–5. These coatings are merely exemplary of antireflection coatings and dichroic coatings which may be utilized as any suitable antireflection coating and dichroic coating may be utilized.

The phase difference introduced as a result of each coating is charted for variation with wavelength. More specifically, the phase differences introduced by the dichroic coating and antireflection coating on Prism R are shown respectively in FIGS. 11 and 13 and the phase difference introduced by the dichroic coating and antireflection coating on Prism G are shown respectively in FIGS. 18 and 20. Additionally, the spectral performance of these coatings as a function of wavelengths are also charted as shown in FIGS. 10 and 12 for Prism R and in FIGS. 17 and 19 for Prism G. Furthermore, the phase difference variation with angle of incidence for a total internal reflection surface is also provided in FIG. 13. Using the data provided in Examples 3A–3D, one skilled in the art can calculate the optical performance of these interference filters at different angles to determine the optimum correction for a particular illumination system by utilizing the technology disclosed in this application.

A system as shown in FIG. 1 and configured as particularly set forth in Examples 3A–3D yet without waveplate compensators would be expected to yield a contrast ratio of about 30:1. As set forth herein, utilizing waveplate compensators typically increases the contrast ratio by at least one order of magnitude. However, the contrast achieved is also dependent on the coatings utilized, the illumination spectrum, the use of a color tuning filter and whether photoptic weighting is included. Photoptic weighting was assumed, as was the use of a uniform illumination source and a color tuning filter with two notches.

Example 3A

Example 3A and FIGS. 7–13 are related to comparative data for red light passing through a color channel such as the color channel defined by first triangular prism R, waveplate compensator 80 and liquid crystal light valve 90 and also light passing through the same channel without the waveplate compensator. The dichroic coating used to select the red light which forms the red color channel had a center wavelength of about 620 nm.

FIG. 7 is a plot of the ellipticity and rotation values for retarder values ranging from 0 to 0.5 of a retarder at an orientation of 0° of a ray, R4, having a wavelength of 630 nm. As the plot shows, the ellipticity and orientation both have a minimum when the retardance value is about 0.20.

FIG. 8 is a pupil map of the polarization state through the first channel or the red light channel with reference to the particular configuration described in FIG. 1, however, without a waveplate compensator. This represents the "off"-pixel through the display system. The resulting polarization state is a combination of the dichroic coating, antireflection coating and total internal reflection surfaces in the channel. A system with infinite contrast ratio would have no ellipticity and an angle of rotation of zero degrees. In this case, there is a significant ellipticity and orientation at the edge of the pupil at the extreme relative pupil positions. The contrast with uniform spectrum, a color tuning filter, dichroic coatings, standard antireflective coatings and photoptic weighting was 50:1. Note, that the direction of orientation is opposite that of Example 1, the uncoated TIR prism, illustrated in FIG. 4, and slightly larger while the ellipticity is considerably larger.

Insertion of a waveplate compensator having a retardance value of 0.20 produces a pupil polarization map as shown in FIG. 9. When the 0.20 waveplate compensator is utilized with uniform spectrum, a color tuning filter, dichroic coatings, standard antireflective coatings and photoptic weighting, the contrast was 678:1.

Tables 2 and 3 provided hereinbelow provide the thickness of the thin film layers and the order of deposition of the antireflection coating and dichroic coating respectively located on the first triangular prism R at 42 and 44. FIGS. 10–13 illustrate the key characteristics of the optical performance of the resulting filter for prism R over the range of visible wavelengths from 400 nm to 700 nm. FIGS. 10–11 are related to the antireflection coating and FIGS. 12–13 are related to the dichroic coating. The antireflective coating deposited on surface 41*a* to yield coating 42 was formed from alternating layers of Ta_2O_5 (H) and SiO_2 (L_1). The coating is applied with the material at the top of the column in Table 2 next to the incident medium and terminates with the material at the bottom of column next to the substrate. The refractive index of the high index material (H), the low index material (L_1), the incident media and the substrate were 2.13, 1.45, 1.0 and 1.52. The thickness of material is in nanometers (nm). The sequence and thickness are provided in Table 2.

TABLE 2

Material	Thickness
L_1	98.62
H	40.86
L_1	32.98
H	23.64

FIG. 10 provides the spectral performance of the antireflection coating 42, at normal incidence, as used on surface 41*a* on prism R. FIG. 11 provides the resulting phase difference over the same wavelength as in FIG. 10 at the triangle.

The dichroic coating deposited on surface 41*b* to yield coating 44 was formed from alternating layers of TiO_2 (H), ZrO_2 (L) and SiO_2 (L_1). The coating is applied with the material at the top of the column in Table 3 next to the incident medium and terminates with the material at the bottom of column next to the substrate. The refractive index of the high index material (H), the low index material (L), the other low index material (L_1), the incident media and the substrate were 2.45, 2.00, 1.45, 1.52 and 1.00. The thickness of material is in nanometers (nm). The sequence and thickness are provided in Table 3.

TABLE 3

Material	Thickness
H	92.55
L	62.32
H	92.17
L	57.97
H	83.54
L	79.59
H	70.85
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	87.00
H	67.94
L	92.32
H	64.60
L	95.52
H	65.55
L	91.27
H	76.21
L_1	86.20

FIG. 12 depicts optical performance of the dichroic filter on the first triangular prism R showing the reflection of unpolarized, s-polarized and p-polarized light over the range of visible wavelengths from 400 nm to 700 nm at an angle of 280. The desirable spectral characteristics of this dichroic filter are as follows: 1) the filter has a reflectance near zero, so that it transmits light, from about 400 nm to about 580 nm, 2) the region, starting at about 580 nm, where the reflectance starts to increase rapidly over about a 20 nm range to near 100 percent, designates the cut on wavelength, 3) The s-polarization and p-polarization states are close to overlapping at the cut on the region, but do not have the same reflectance value until about 630 nm, at which both polarization states have a maximum reflectance close to 100 percent. In the ideal case, the s-polarization and p-polarization state reflectance would overlap completely at the cut on wavelength to the maximum reflectance value defining the red channel. While this can be done at a single angle of incidence, in practice some compromise must be made over the range of cone angles representing the incident illumination.

FIG. 13 illustrates the resulting phase difference between the s-polarization and p-polarization states over the same wavelength range in FIG. 12. The phase difference in transmission is relatively constant, between zero and (-) 30° over the dichroic coatings low reflection, high transmission, region of 400 nm to about 580 nm. At the cut on wavelength the phase difference undergoes a transition changing from about (-) 50° to about (+) 130°, then decreasing in slope over the region of high reflection, about 600 nm to 680 nm. The waveplate compensator is effective for the latter range of wavelengths in the red color channel, where the phase difference is relatively constant with wavelength.

FIG. 12 illustrates the desired reflection of the s and p polarization components required to obtain a high brightness and contrast image. This filter, for the red channel, has a pass or low reflection region from 450 up to 580 nm where a transition occurs to a "stop" or high reflection wavelength range. In the preferred embodiments of this invention, the wavelength range of the transition region is narrow and the reflectivity is as high as possible in the "stop" region and zero in the "pass" such that the red image channel information does not receive the contribution from corresponding pixels in the green or blue channels. Furthermore, the coatings are ideally non-polarizing at the angle of incidence for the nominal rays. Accordingly, the s and the p-polarization components of transmitted light should overlap starting at the transition region continuing on through the "stop" band. Optimizing the non-polarizing characteristics results in the maximum display brightness. Both the s-polarization and p-polarization states must be reflected to exit the prism and be transmitted by a polarization selecting element for projection to the viewing screen, therefore, the average transmitted intensity is proportional to the product of the s and p reflectivities at a given wavelength. Several design methods can be used to achieve non-polarizing dichroic coatings, however, the non-polarizing characteristic is limited to a fixed angle of incidence. In practice, the system must be optimized to deal with the range of divergent angles. This requires a compromise between two characteristic properties of interference coatings at increasing angles of incidence, 1) the shift of the spectral curve shape towards shorter wavelengths, and 2) increased separation between the s-polarization and p-polarization states. This compromise can be made without significant deterioration to image contrast and brightness by removing the polarizing transition region to gain a broad wavelength region used to achieve the channels characteristic color. Example 3D sets forth a technique for achieving this objective.

Example 3B

This example and FIGS. 14–20 are related to comparative data for green light passing through a color channel such as the color channel defined by second triangular prism G, waveplate compensator **100** and liquid crystal light valve **110** and also light passing through the same channel without the waveplate compensator. The dichroic coating used in prism G, for the green channel, has a center wavelength of about 540 nm.

FIG. 14 is a plot of the ellipticity and rotation values for retarder values ranging is from 0 to 0.5 of a retarder at an orientation of 0° of a ray, R4, at a wavelength of 550 nm. As the plot shows, the ellipticity and orientation both have a minimum when the retardance value is about 0.20. The ellipticity and orientation also both have approximately a minimum at a retardance value of 0.20.

FIG. 15 is a pupil map of the polarization state through the green light channel with reference to the particular configuration described in FIG. 1. This represents the "off"-pixel through the display system. The resulting polarization state is a combination of the dichroic coating, antireflection coating and total internal reflection surfaces in the channel. A system with infinite contrast ratio would have no ellipticity and an angle of rotation of zero degrees. In this case, there is a slight ellipticity at the edge of the pupil as well as relatively large orientation, with respect to the prism R, the pupil diagram illustrated in FIG. 8. The contrast with uniform spectrum, a color tuning filter, dichroic coatings, standard antireflective coatings and photoptic weighting was 24:1.

Insertion of a waveplate compensator having a retardance value of 0.20 produces a pupil polarization map as shown in

FIG. 16. When the 0.20 waveplate compensator is utilized with uniform spectrum, a color tuning filter, dichroic coatings, standard antireflective coatings and photoptic weighting, the contrast was 538:1.

Tables 4 and 5 provided hereinbelow provide the thickness of the thin film layers and the order of deposition of the antireflection coating and dichroic coating respectively located on the second triangular prism G at 52 and 54. FIGS. 17–20 illustrate the key characteristics of the optical performance of the resulting filter for prism G over the range of visible wavelengths from 400 nm to 700 nm. FIGS. 17–18 are related to the antireflection coating and FIGS. 19–20 are related to the dichroic coating.

The antireflective coating deposited on surface 51*a* to yield coating 52 was formed from alternating layers of Ta_2O_5 (H) and SiO_2 (L_1). The coating is applied with the material at the top of the column in Table 4 next to the incident medium and terminates with the material at the bottom of the column next to the substrate. The refractive index of the high index material (H), the low index material (L_1), the incident media and the substrate were 2.13, 1.45, 1.0 and 1.52. The thickness of material is in nanometers (nm). The sequence and thickness are provided in Table 4.

TABLE 4

Material	Thickness
L_1	98.32
H	59.72
L_1	25.38
H	24.98

FIG. 17 provides the spectral performance of antireflection coating 52 on surface 51*a* at 45° incidence, representing the chief ray entering prism G after passing through the dichroic coating 44 on surface 41*b* of prism R. Under these conditions there is a difference in intensity between the s-polarization and p-polarization vectors, as well as a wavelength dependent phase, which is provided in FIG. 18.

The dichroic coating deposited on surface 51*b* to yield coating 54 was formed from alternating layers of TiO_2 (H) and ZrO_2 (L). The coating is applied with the material at the top of the column in Table 5 next to the incident medium and terminates with the material at the bottom of the column next to the substrate. The refractive index of the high index material (H), the low index material (L), the incident media and the substrate were 2.45, 2.00, 1.52 and 1.52. The thickness of material is in nanometers (nm). The sequence and thickness are provided in Table 5.

TABLE 5

Material	Thickness
L	38.33
H	54.56
L	70.12
H	57.77
L	70.33
H	52.55
L	70.90
H	53.90
L	67.51
H	53.90
L	67.51
H	53.90
L	67.51

TABLE 5-continued

Material	Thickness
H	53.90
L	67.51
H	53.90
L	70.91
H	52.55
L	70.34
H	57.78
L	70.12
H	54.55
L	38.32

FIG. 19 depicts optical performance of the dichroic filter on the second triangular prism G showing the reflection of unpolarized, s-polarized and p-polarized light over the range of visible wavelengths from 400 nm to 700 nm at an angle of 10.250°. FIG. 20 illustrates the resulting phase difference between the s-polarization and p-polarization states over the same wavelength range in FIG. 19.

Example 3C

This example and FIGS. 21–22 are related to data for blue light passing through a color channel such as the color channel defined by first quadrangular prism B and liquid crystal light valve 130 without a waveplate compensator such as waveplate compensator 120. The blue light had wavelength of about 450 nm.

FIG. 21 is a plot of the ellipticity and rotation values for retarder values ranging from 0 to 0.5 of a retarder at an orientation of 0° of a ray, R4, at a wavelength of 450 nm. As the plot shows, the ellipticity and orientation are near zero over the entire retardation range.

FIG. 22 is a pupil map of the polarization state through the third channel or the blue light channel with reference to the particular configuration described in FIG. 1, however, without a waveplate compensator. In this case, there is no ellipticity or orientation. The contrast with uniform spectrum, a color tuning filter, zero phase dichroic coatings, standard antireflective coatings and photoptic weighting was 3000:1. Accordingly, a waveplate compensator is not required.

Example 3D

Example 3D provides data related to the performance of a color tuning filter utilized in the system described in Examples 3A–3C. Such a color tuning filter may be utilized at a location in the system to filter the incoming light. The notches, low transmittance regions, of the filter are designed to correspond to the transition zones of the dichroic coatings. More specifically, the notches of the filter are designed to correspond to the transition zones of the dichroic coatings such as the dichroic coating in the red channel described in Example 3A, as will be set forth below in further detail. Preferably, the filter is located in the region of illumination as shown in FIG. 1 at 12. The characteristics of the notch filter are selected to operate with the preferred dichroic filters such that the correcting effect of the waveplate compensator is maximized for contrast of each color channel.

Preferably, the notch filter has a very steep slope from the cut on to its first peak wavelength, to selectively remove only the limited range of wavelengths so as not to degrade the brightness of the selected color channel. In a more preferred embodiment, the notch filter further defines the wavelength ranges of each color channel to provide the

proper color purity and to insure that it is not compromised by chromatic variations in the light source. It is most preferred to utilize a single filter element that corrects for all color channels. The most preferred filter element is a thin film interference coating notch filter, the spectral performance of which is depicted in FIG. 23. This filter has the same spectral performance in transmission for unpolarized light, s-polarized light and p-polarized light for the notch filter, since it is used at normal incidence. The interference notch filter has an extremely narrow transition region which is positioned at a wavelength such that the portion of the reflected wavelengths which are not correctable with a waveplate compensator are blocked and do not effect the image contrast or brightness. The notch filter rejects the cut on region wavelengths, which cannot be corrected by the waveplate compensator due to the change in phase difference. The notch filter permits the use of non zero phase difference dichroic filters to selectively limited wavelength regions.

Interference notch filters are preferred over absorbing color filters. Absorbing color filters have broad rather than steep slopes required for very selective rejection. One notch filter can be used for the entire display device, since interference filters can be made with narrow notch widths and steep slopes for the selective rejection of the transition zones in the dichroic filters. However, separate absorbing filters may be inserted in each color channel. The filter in FIG. 23 is exemplary of these characteristics, having less than 10 percent transmission for the region of about 575–600 nm, 50 percent transmission at 610 nm and greater than 95 percent transmission up to about 680 nm.

FIGS. 19 and 20 illustrates the spectral characteristics of the dichroic filter 54 on surface 51*b* for the second triangular prism G that act in cooperation with the preferred notch filter over the range of visible wavelengths from 400 nm to 700 nm as shown in FIG. 23, to obtain a high brightness and contrast image. The notch filter also defines the blue channel having about 95 percent transmission from about 400 to 465 nm. Thus, it can be seen that the transition regions of the dichroic coatings, which have changes in reflected phase difference do not interfere with the image contrast, being blocked by the stop bands in the notch filter.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed and desired to be secured by United States Letters Patent is:

1. A waveplate compensator for use in an image projection system which utilizes color splitting means for separating a polarized component of light into at least two separate color beams, the waveplate compensator comprising:

a birefringent material having a thickness,

said waveplate compensator having a retardance which is dependent on the birefringent material and the thickness of the birefringent material,

said retardance being selected to retard a color beam by a wave value at which an approximate minimum occurs for both ellipticity and elliptical polarization orientation of the color beam as caused by polarization rotation of a portion of the color beam by a color splitting means,

whereby placement of the waveplate compensator in the optical path between a color splitting means and an imaging means substantially eliminates any portion of light that undergoes polarization rotation by the color splitting means.

2. A waveplate compensator as recited in claim 1, wherein the birefringent material is selected from the group consisting of quartz, calcite, mica.

3. A waveplate compensator as recited in claim 1, wherein the birefringent material is an organic polymeric plastic having different indices of refraction for different crystallographic axes.

4. A waveplate compensator as recited in claim 1, wherein the birefringent material is a liquid crystal cell.

5. A waveplate compensator as recited in claim 1, wherein the waveplate compensator means sufficiently eliminates any portion of light that undergoes polarization rotation by a color splitting means in a reflective imaging system that the resulting contrast ratio of the system is at least about an order of magnitude greater than a contrast ratio of the same reflective imaging system without a waveplate compensator.

6. A waveplate compensator as recited in claim 1, wherein the waveplate compensator is configured to be positioned in an optical path between a beam exit location of a color splitting means and an imaging means.

7. A waveplate compensator as recited claim 1, wherein the waveplate compensator is configured to be coupled to a color splitting means.

8. A waveplate compensator as recited claim 1, wherein the waveplate compensator is configured to be coupled to an imaging means.

9. A waveplate compensator as recited in claim 1, wherein the waveplate compensator is substantially separated from the image plane.

10. A waveplate compensator for use in an image projection system which utilizes color splitting means for separating a polarized component of light into at least two separate color beams, the waveplate compensator comprising:

a birefringent material having a thickness,

said waveplate compensator having a retardance which is dependent on the birefringent material and the thickness of the birefringent material,

said retardance being selected to retard a color beam by a wave value which corresponds with a calculated polarization rotation elimination retardance value,

said calculated polarization rotation elimination retardance value being the value at which both ellipticity and elliptical polarization orientation of the color beam as caused by polarization rotation of a portion of the color beam by a color splitting means are both at approximately a minimum,

whereby placement of the waveplate compensator in the optical path between a color splitting means and an imaging means substantially eliminates any portion of light that undergoes polarization rotation by the color splitting means.

11. A waveplate compensator as recited in claim 10, wherein the birefringent material is selected from the group consisting of quartz, calcite, mica.

12. A waveplate compensator as recited in claim 10, wherein the birefringent material is an organic polymeric plastic having different indices of refraction for different crystallographic axes.

13. A waveplate compensator as recited in claim 10, wherein the birefringent material is a liquid crystal cell.

14. A waveplate compensator as recited in claim 10, wherein the waveplate compensator means sufficiently eliminates any portion of light that undergoes polarization rotation by a color splitting means in a reflective imaging system that the resulting contrast ratio of the system is at least about an order of magnitude greater than a contrast ratio of the same reflective imaging system without a waveplate compensator.

15. A waveplate compensator as recited in claim 10, wherein the waveplate compensator is configured to be positioned in an optical path between a beam exit location of a color splitting means and an imaging means.

16. An image projection system comprising:

(a) polarizing means for polarizing light to transmit a first polarized component of light in a first polarization state;

(b) color splitting means for separating the first polarized component of light into three primary color beams including a red beam, a green beam, and a blue beam,

(i) wherein each of the three beams exits primarily in the first polarization state from the color splitting means at three separate beam exit locations,

(ii) wherein said color splitting means causes at least one of the three beams to have residual elliptical polarization due to polarization rotation of a portion of the beam such that at least one of the three beams has an ellipticity and an elliptical polarization orientation;

(c) three imager means for modulating a polarization state of each of the three primary color lights,

(i) wherein the three imager means are positioned such that each imager means receives one of the three primary color beams; and

(d) at least one waveplate compensator means for retarding at least one of the three primary color beams to achieve a predetermined phase difference,

(i) wherein the waveplate compensator means is positioned such that the waveplate compensator means is in an optical path between one of the three light exit locations of the color splitting means and one of the three imager means,

(ii) wherein the waveplate compensator means has a retardance selected to retard the respective primary color beam by a wave value at which both the ellipticity and the elliptical polarization orientation of the respective beam are approximately at a minimum, thereby substantially eliminating any portion of light that undergoes polarization rotation by said color splitting means.

17. A system as recited in claim 16, further comprising light source means for providing light to the polarizing means.

18. A system as recited in claim 16, wherein the light has wavelength ranges and wherein the system further comprises notch filter means for tuning the wavelength ranges of the light such that the light entering the color splitting means has selected wavelength ranges.

19. A system as recited in claim 16, wherein the light has wavelength ranges and wherein the system further comprises notch filter means for tuning the wavelength ranges of the light such that the notch filter reflects incidental light at wavelengths having substantially non-constant phase retardance and substantially transmits light having a substantially constant phase retardance.

20. A system as recited in claim 16, wherein the polarizing means is a polarizing beam splitter.

21. A system as recited in claim 16, wherein the polarizing means is a polarizing cubic beam splitter.

22. A system as recited in claim 16, wherein the color splitting means is a Philips prism having at least one surface with a dichroic coating.

23. A system as recited in claim 16, wherein the color splitting means is a Philips prism having at least one surface with a dichroic coating with a nonzero phase retardance.

24. A system as recited in claim 16, wherein the color splitting means is a Philips prism having at least one surface with a dichroic coating with a nonzero phase retardance and a substantially constant phase retardance for the wavelength of light encountering the dichroic coating.

25. A system as recited in claim 16, wherein the color splitting means is selected from the group consisting of beamsplitter cubes, X-prisms, L-prisms, and flat tilted plate dichroic mirrors.

26. A system as recited in claim 16, wherein the three imager means are three liquid crystal light valves.

27. A system as recited in claim 16, wherein the waveplate compensator means is a waveplate compensator formed from a birefringent material.

28. A system as recited in claim 16, wherein the waveplate compensator means is formed from a material selected from the group consisting of quartz, calcite, mica, organic polymeric plastics having different indices of refraction for different crystallographic axes, and a liquid crystal cell.

29. A system as recited in claim 16, wherein the at least one waveplate compensator means is coupled to the color splitting means.

30. A system as recited in claim 16, wherein the at least one waveplate compensator means is coupled to the imager means.

31. A system as recited in claim 16, wherein the at least one waveplate compensator means sufficiently eliminates any portion of light that undergoes polarization rotation by said color splitting means such that the resulting contrast ratio of said reflective imaging system is at least about an order of magnitude greater than a contrast ratio of a reflective imaging system such as said reflective imaging system without polarization correction means.

32. A system as recited in claim 16, wherein the at least one waveplate compensator means comprises at least two waveplate compensators, and wherein each waveplate compensator has a wave value specifically determined in relation to the respective beam received by each waveplate compensator.

33. A system as recited in claim 16, wherein said retardance of said at least one wave compensating means is selected based on polarization vector modifying characteristics of said color splitting means.

34. A system as recited in claim 16, wherein said retardance of said at least one wave compensating means is selected based on polarization vector modifying characteristics of said polarizing means and said color splitting means.

35. A system as recited in claim 16, further comprising a convergent light source, wherein said retardance of said at least one wave compensating means is selected based on polarization vector modifying characteristics of said convergent light source, said polarizing means, and said color splitting means.

36. A system as recited in claim 16, wherein the polarizing means and the color separation element impart a dispersion in retardance, and wherein the at least one waveplate compensator means has a dispersion in retardance substantially equal to the dispersion in phase retardance imparted by the polarizing means and the color separation element.

37. A system as recited in claim 16, wherein said first polarized component of light comprises a plurality of skew

rays each having a first polarization vector, the skew rays having been directionally modified by said polarizing means, and

wherein the at least one waveplate compensator means modifies the polarization state of the skew rays passing therethrough, such that a second component of light having a second polarization state enters into the color splitting element with each skew ray having a second polarization vector substantially orthogonal to the first polarization vector of the respective skew ray.

38. An image projection system comprising:

(a) polarizer for polarizing light to transmit a first polarized component of light in a first polarization state;

(b) color splitter for separating the first polarized component of light into three primary color beams including a red beam, a green beam, and a blue beam,

(i) wherein each of the three beams exits primarily in the first polarization state from the color splitter at three separate beam exit locations,

(ii) wherein said color splitter causes at least one of the three beams to have residual elliptical polarization due to polarization rotation of a portion of the beam such that at least one of the three beam has an ellipticity and an elliptical polarization orientation;

(c) three reflective imagers for modulating a polarization state of each of the three primary color lights and for reflecting the beam thus modulated,

(i) wherein the three reflective imagers are positioned such that each reflective imager receives one of the three primary color beams and reflects the respective beam in a second polarization state back into the color splitter; and

(d) at least one waveplate compensator for retarding at least one of the three primary color beams to achieve a predetermined phase difference.

(i) wherein the waveplate compensator is positioned in an optical path between one of the three light exit locations of the color splitter and one of the three reflective imagers,

(ii) wherein the waveplate compensator has a retardance selected to retard the respective primary color beam by a wave value at which both the ellipticity and the elliptical polarization orientation of the respective beam are approximately at a minimum, thereby substantially eliminating any portion of light that undergoes polarization rotation by said color splitter.

39. A system as recited in claim 38, further comprising a light source for providing light to the polarizer.

40. A system as recited in claim 38, wherein the light has wavelength ranges and wherein the system further comprises a notch filter for tuning the wavelength ranges of the light such that the light entering the color splitter has selected wavelength ranges.

41. A system as recited in claim 38, wherein the light has wavelength ranges and wherein the system further comprises a notch filter for tuning the wavelength ranges of the light to reflect incidental light with substantially nonconstant phase retardance and substantially transmits light having a substantially constant phase retardance such that the light entering the color splitter has selected wavelength ranges.

42. A system as recited in claim 38, wherein the polarizer is a polarizing beam splitter.

43. A system as recited in claim 38, wherein the polarizer is a polarizing cubic beam splitter.

44. A system as recited in claim 38, wherein the color splitter is a Philips prism having at least one surface with a dichroic coating.

45. A system as recited in claim 38, wherein the color splitter is a Philips prism having at least one surface with a dichroic coating with a nonzero phase retardance.

46. A system as recited in claim 38, wherein the color splitting means is a Philips prism having at least one surface with a dichroic coating with a nonzero phase retardance and a substantially constant phase retardance for the wavelength of light encountering the dichroic coating.

47. A system as recited in claim 38, wherein the color splitter is selected from the group consisting of beamsplitter cubes, X-prisms, L-prisms, and flat tilted plate dichroic mirrors.

48. A system as recited in claim 38, wherein the three reflective imagers are three liquid crystal light valves.

49. A system as recited in claim 38, wherein the waveplate compensator is formed from a birefringent material selected from the group consisting of quartz, calcite, mica, organic polymeric plastics having different indices of refraction for different crystallographic axes, and a liquid crystal cell.

50. A system as recited in claim 38, wherein the at least one waveplate compensator is coupled to the color splitter.

51. A system as recited in claim 38, wherein the at least one waveplate compensator means is coupled to the imagers.

52. A system as recited in claim 38, wherein the at least one waveplate compensator sufficiently eliminates any portion of light that undergoes polarization rotation by said color splitter such that the resulting contrast ratio of said reflective imaging system is at least about an order of magnitude greater than a contrast ratio of a reflective imaging system such as said reflective imaging system without polarization correction means.

53. A system as recited in claim 38, wherein the at least one waveplate compensator comprises at least two waveplate compensators, and wherein each waveplate compensator has a wave value specifically determined in relation to the respective beam received by each waveplate compensator.

54. A system as recited in claim 38, wherein said retardance of said at least one waveplate compensator is selected based on polarization vector modifying characteristics of said color splitter.

55. A system as recited in claim 38, wherein said retardance of said at least one waveplate compensator is selected based on polarization vector modifying characteristics of said polarizer and said color splitter.

56. A system as recited in claim 38, further comprising a convergent light source, wherein said retardance of said at least one wave compensating means is selected based on polarization vector modifying characteristics of said convergent light source, said polarizer and said color splitter.

57. A system as recited in claim 38, wherein the polarizer and the color splitter impart a dispersion in retardance, and wherein the at least one waveplate compensator has a dispersion in retardance substantially equal to the dispersion in phase retardance imparted by the polarizer and the color splitter.

58. A system as recited in claim 38, wherein said first polarized component of light comprises a plurality of skew rays each having a first polarization vector, the skew rays having been directionally modified by said polarizer, and

wherein the at least one waveplate compensator modifies the polarization state of the skew rays passing therethrough, such that a second component of light

having a second polarization state enters into the color splitter with each skew ray having a second polarization vector substantially orthogonal to the first polarization vector of the respective skew ray.

59. A method of manufacturing a waveplate compensator for use in an image projection system which utilizes color splitting means for separating a polarized component of light into at least two separate color beams, the method comprising:

identifying a desired retardance value at which an approximate minimum occurs for both ellipticity and elliptical polarization orientation of light as caused by polarization rotation of a portion of the light by a color splitting means in an image projection system, and

providing a waveplate compensator having a retardance value which corresponds with the desired retardance value identified as resulting in an approximate minimum for both the ellipticity and elliptical polarization orientation of the light.

60. A method as recited in claim 59, wherein said identifying step is achieved by calculating the ellipticity and elliptical polarization orientation.

61. A method as recited in claim 59, wherein said identifying step is achieved by measuring properties related to the ellipticity and elliptical polarization orientation and then calculating the ellipticity and elliptical polarization orientation based on the measured properties.

62. A method as recited in claim 59, wherein said providing step is achieved by selecting a type of birefringent material to be used as the waveplate compensator, identifying an approximate thickness of the selected type of birefringent material which yields a retardance value corresponding with the desired retardance value, and providing the selected type of birefringent material with the identified thickness and in sizes appropriate for use as a waveplate compensator.

63. A method of manufacturing a waveplate compensator for use in an image projection system which utilizes color splitting means for separating a polarized component of light into at least two separate color beams, the method comprising:

determining values, at retardance value intervals, for both ellipticity and elliptical polarization orientation of light as caused by polarization rotation of a portion of the light by a color splitting means in an image projection system,

identifying a desired retardance value at which an approximate minimum occurs for both the ellipticity and the elliptical polarization orientation of the light, and

providing a waveplate compensator having a retardance value which corresponds with the retardance value identified as resulting in an approximate minimum for both the ellipticity and elliptical polarization orientation of the light, whereby the waveplate compensator may be placed in an optical path between a color splitting means and an imaging means to substantially eliminate any portion of light that undergoes polarization rotation by the color splitting means.

64. A method as recited in claim 63, wherein said retardance value intervals range from 0 to 0.5.

65. A method as recited in claim 63, wherein said determining step is achieved by calculating the ellipticity and elliptical polarization orientation.

66. A method as recited in claim 63, wherein said determining step is achieved by:

determining a pupil size of a cone of light as the light is incident in an image projection system at a location intended for placement of a waveplate compensator,

determining a path of at least one ray,

calculating the Stokes parameters, and

calculating both the ellipticity and elliptical polarization orientation of light at retardance value intervals.

67. A method as recited in claim 63, wherein said determining step is achieved by measuring properties related to the ellipticity and elliptical polarization orientation and then calculating the ellipticity and elliptical polarization orientation based on the measured properties.

68. A method as recited in claim 63, wherein said identifying step is achieved by plotting the determined values of the ellipticity and elliptical polarization orientation.

69. A method as recited in claim 63, wherein said providing step is achieved by selecting a type of birefringent material to be used as the waveplate compensator, identifying an approximate thickness of the selected type of birefringent material which yields a retardance value corresponding with the desired retardance value, and providing the selected type of birefringent material with the identified thickness and in sizes appropriate for use as a waveplate compensator.

70. A method as recited in claim 63, further comprising the step of determining a retardance value which gives the largest integrated contrast through an iterative process by redetermining the ellipticity and elliptical polarization orientation at smaller intervals than the retardance value intervals used in the determining step.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,986,815

DATED : Nov. 16, 1999

INVENTOR(S) : Brett Bryars

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Cover Page, References Cited, please insert the following references:

5,668,664	Shishido
5,777,673	Yoshikawa

Cover Page, Abstract, line 15, change "increases" to --increasing--

Col. 1, line 58, change "(100%/2%=50:1." to --(100%/2%=50:1).--

Col. 2, line 58, after "tilted" change "surface" to --surfaces--

Col. 8, line 4, after "700" change "run" to --nm--

Col. 9, line 49, after "is in" insert --the--

Col. 11, line 57, change "tug" to --tuning--

Col. 12, line 62, after "Philips" delete "is"

Col. 14, line 11, change "An" to --Δn--

Col. 14, line 66, after "and" insert --S_3--

Col. 15, line 32, before "is" delete "and"

Col. 16, line 65, after "of" delete "the"

Col. 21, line 36, change "280" to --28°--

Col. 22, line 33, change "channels" to --channel's--

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,986,815

DATED : Nov. 16, 1999

INVENTOR(S) : Brett Bryars

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 22, line 46, after "ranging" delete "is"

Col. 29, line 24, after "three" change "beam" to --beams--

Signed and Sealed this

Sixth Day of February, 2001

Attest:

Q. TODD DICKINSON

Attesting Officer

Director of Patents and Trademarks

C. JP Patent Publication 6,144,498 (Bryars '498)

US006144498A

United States Patent [19]

Bryars et al.

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[54] COLOR SEPARATION PRISM ASSEMBLY AND METHOD FOR MAKING SAME

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[21] Appl. No.: 09/321,363

[22] Filed: May 27, 1999

Related U.S. Application Data

[60] Provisional application No. 60/088,922, Jun. 11, 1998.

[51] Int. Cl.^{7} G02B 27/14

[52] U.S. Cl. 359/634; 359/638; 348/338

[58] Field of Search 348/338, 337; 359/634, 637, 638, 833

[56] References Cited

U.S. PATENT DOCUMENTS

2,392,978	1/1946	Dimmick	88/1
3,659,918	5/1972	Tan	350/166
4,009,941	3/1977	Verdijk et al.	350/173
4,084,180	4/1978	Stoffels et al.	358/55
4,913,528	4/1990	Hasegawa	350/286
5,014,121	5/1991	Hasegawa et al.	358/55
5,327,289	7/1994	Watanabe et al.	359/634
5,418,769	5/1995	Inoue	369/112
5,621,486	4/1997	Doany et al.	348/756
5,644,432	7/1997	Doany	359/634
5,658,060	8/1997	Dove	353/33
5,671,993	9/1997	Shikama	353/77
5,900,984	5/1999	Yamanaka et al.	359/638

FOREIGN PATENT DOCUMENTS

0837351 A2	4/1998	European Pat. Off. .
3-150523	6/1991	Japan .
9-211209	8/1997	Japan .

OTHER PUBLICATIONS

Keating, Michael P., "*Geometric, Physical & Visual Optics*," 1988, Butterworths, Boston, MA, pp. 139–142.

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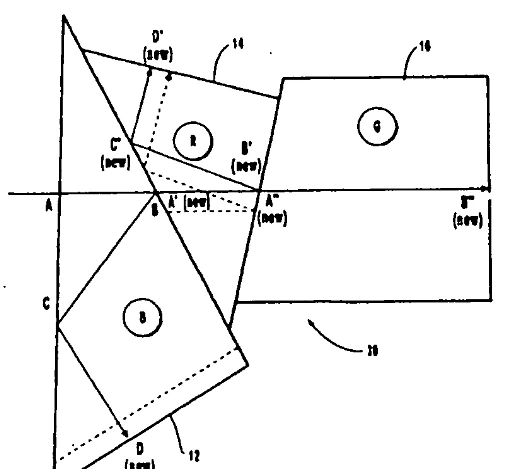
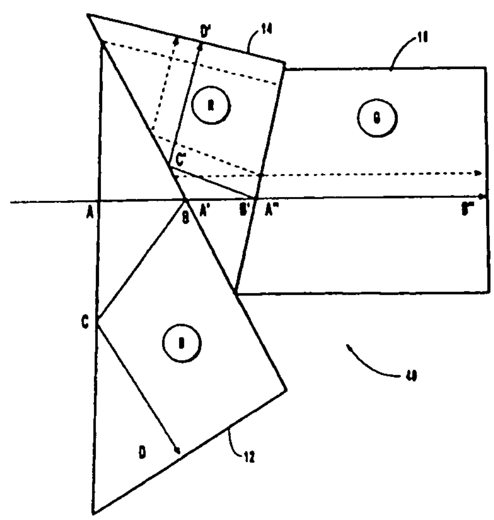
[57] ABSTRACT

A color separation device useful in information display systems is assembled from three prisms in an arrangement that provides for air equivalent thickness adjustment for each color. The air equivalent thickness adjustment provides for the correction of deviations in any of the three prisms, as well as providing a method to correct for the chromatic aberration arising from other optical elements in the information display system. The color separation device improves image quality and provides opportunities to lower the display system cost by using low tolerance components and/or plastic optical components normally having a high chromatic aberration.

35 Claims, 8 Drawing Sheets





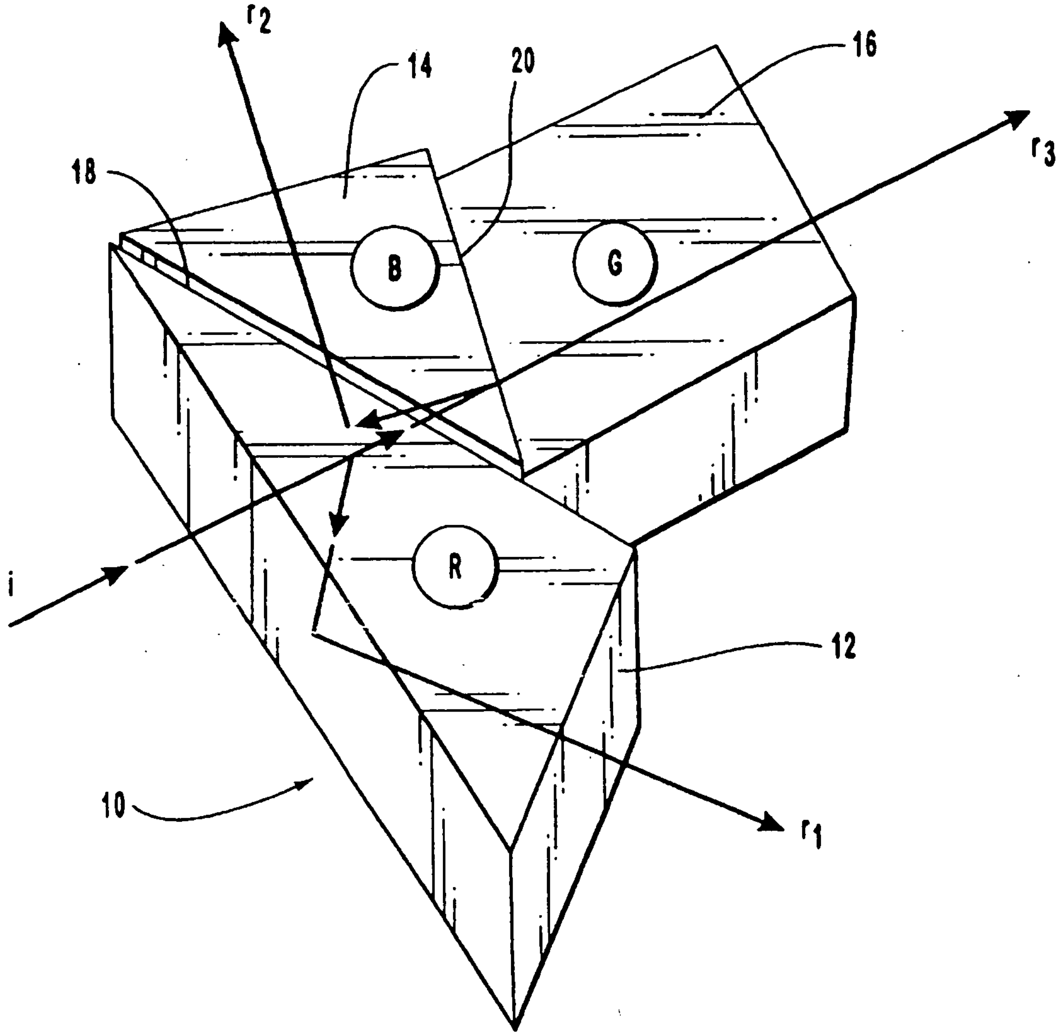


FIG. 1
(PRIOR ART)

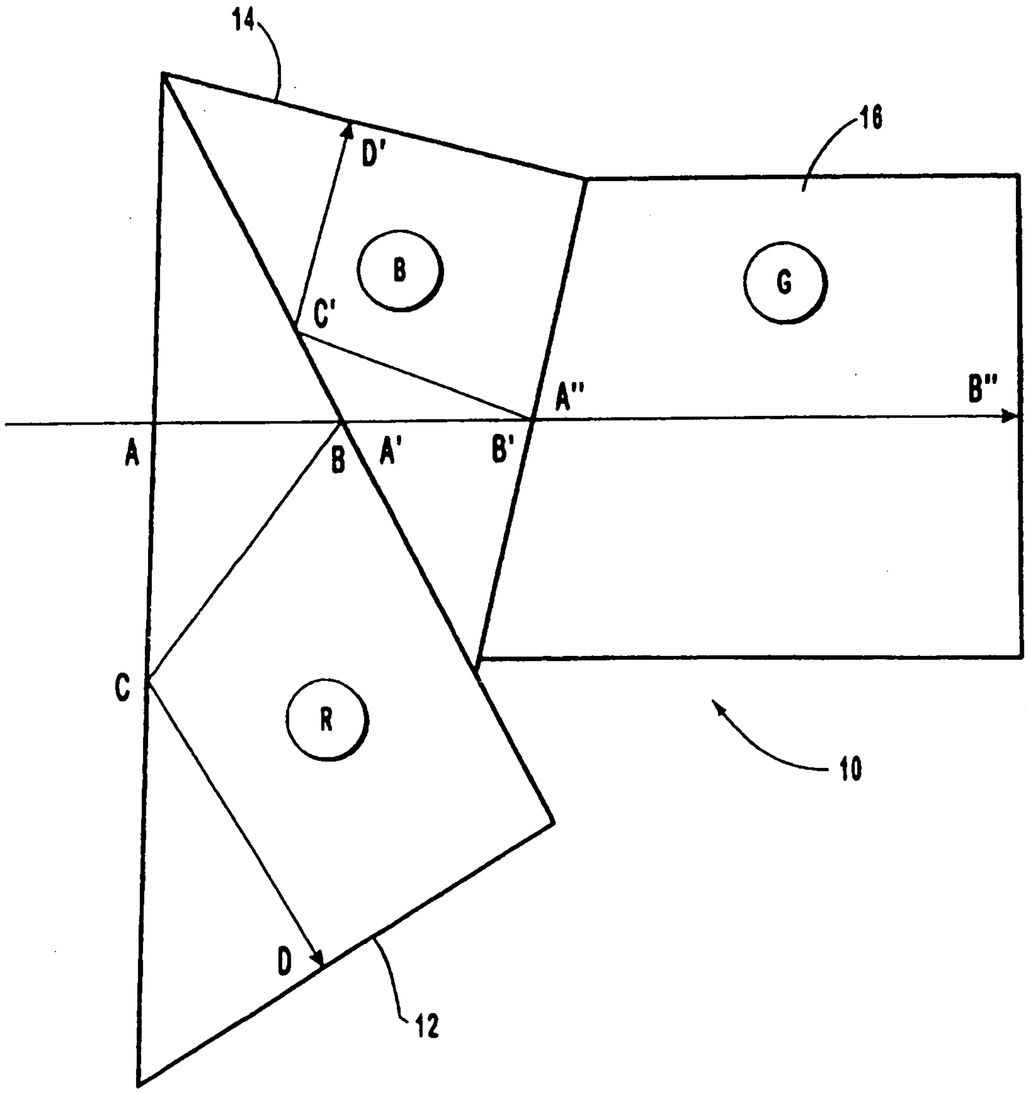


FIG. 3
(PRIOR ART)

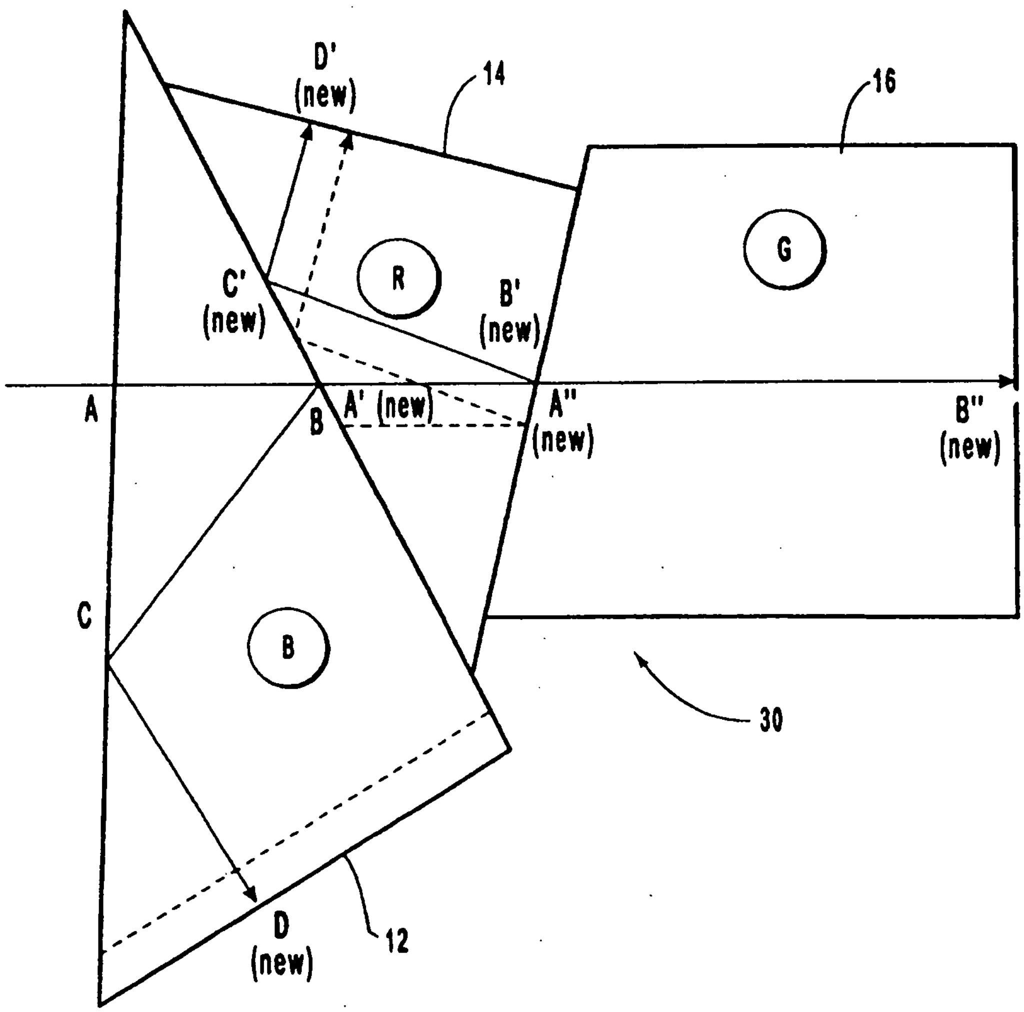


FIG. 4

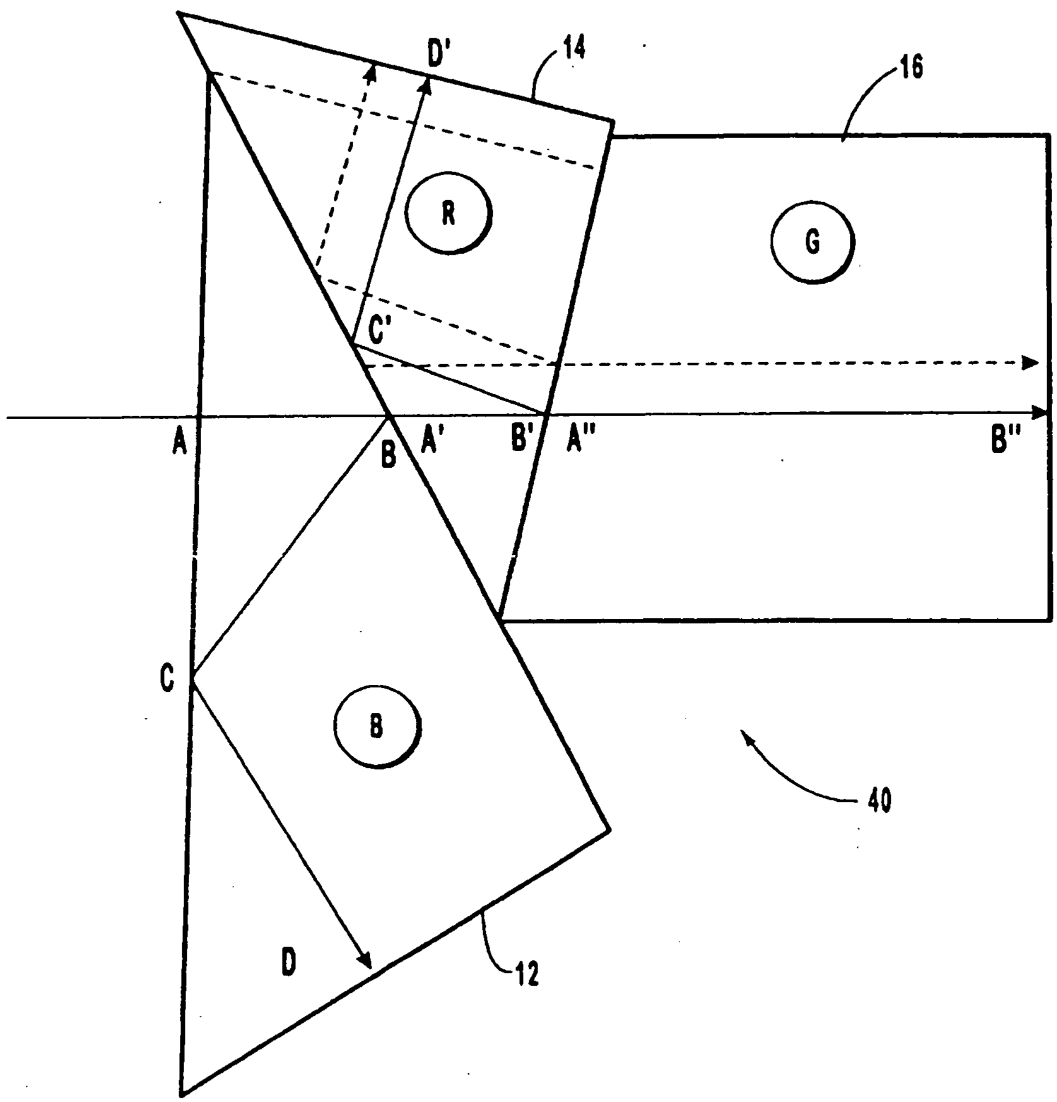


FIG. 5

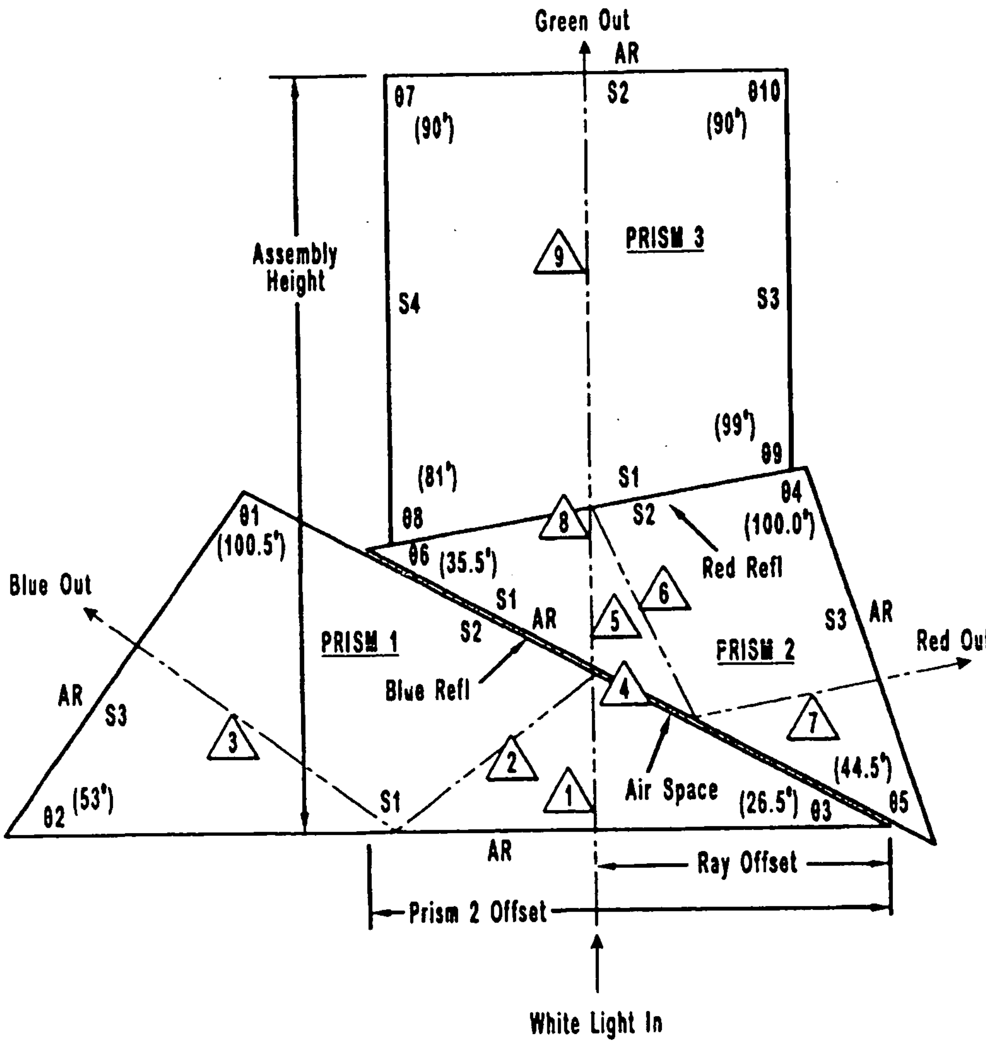

Green Out
AR
θ7
(90°)
S2
θ10
(90°)
Assembly Height
9
PRISM 3
S4
S3
(99°)
θ9
(81°)
S1
θ8
8
S2
θ4
(100.0°)
θ1
(100.5°)
θ6 (35.5°)
Red Refl
Blue Out
6
S1
AR
5
S3
AR
PRISM 1
S2
PRISM 2
Red Out
Blue Refl
4
AR
S3
7
3
2
Air Space
(44.5°)
1
θ2 (53°)
S1
(26.5°) θ3
θ5
AR
Ray Offset
Prism 2 Offset
White Light In

FIG. 6

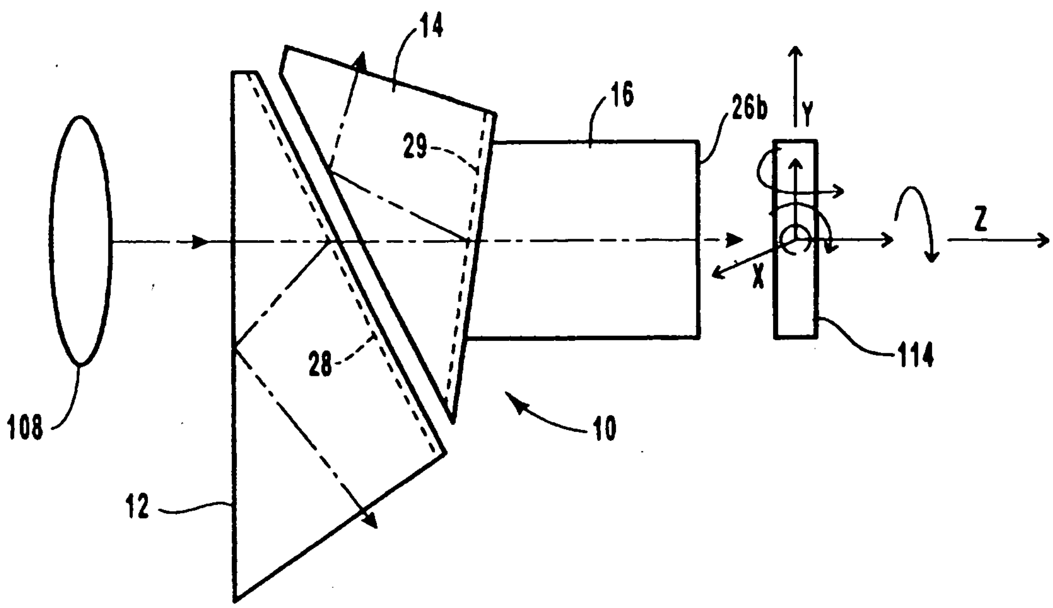


FIG. 7A
(PRIOR ART)

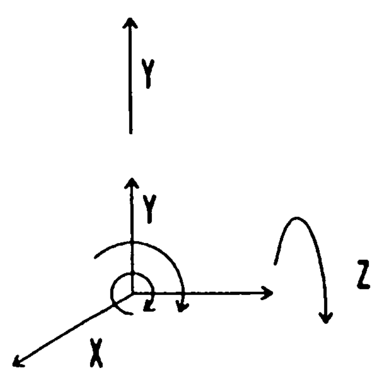


FIG. 7B

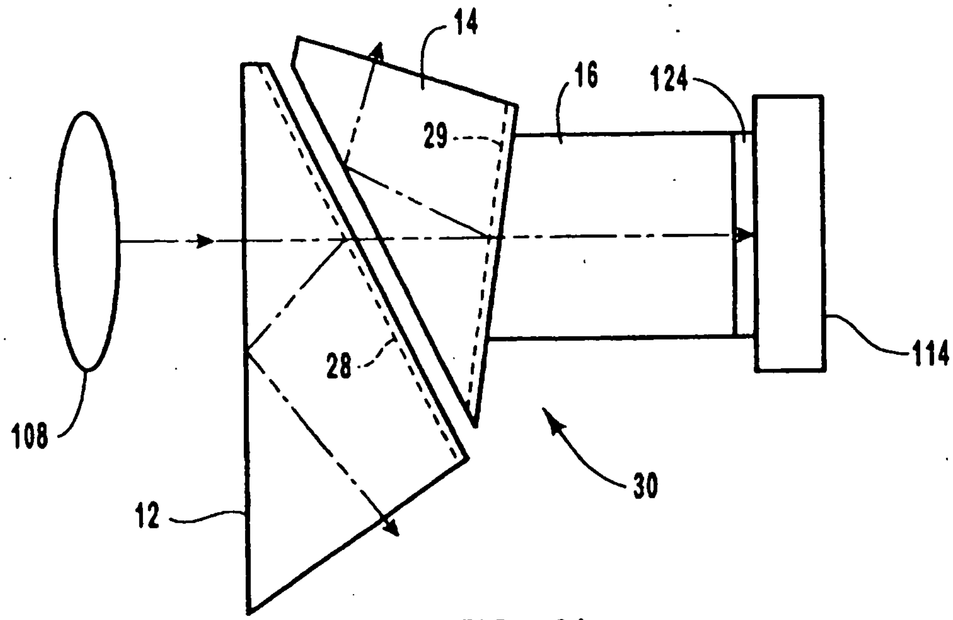


FIG. 8A

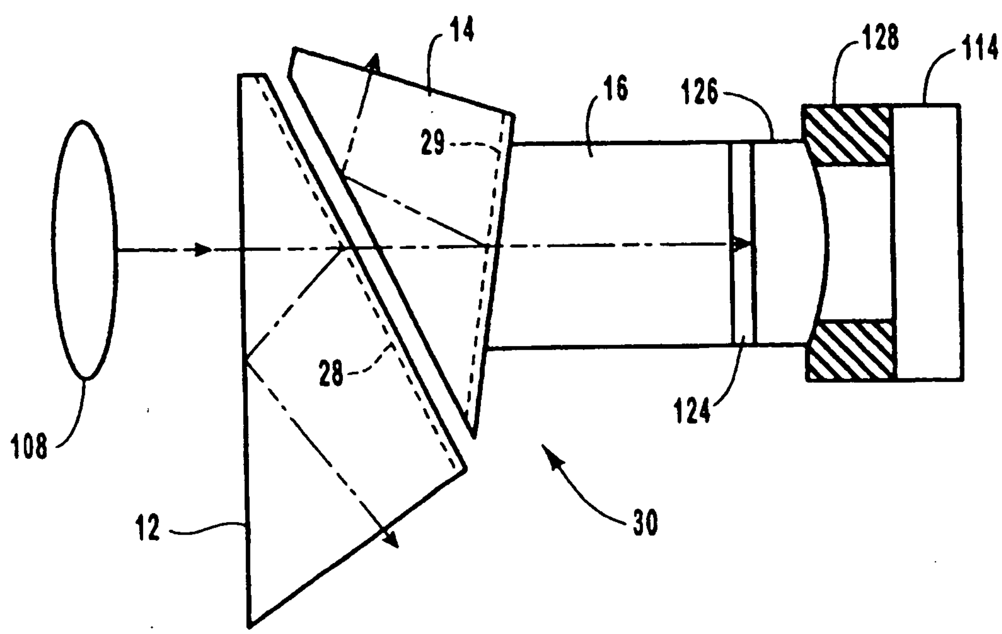


FIG. 8B

COLOR SEPARATION PRISM ASSEMBLY AND METHOD FOR MAKING SAME

This application claims the benefit of priority to U.S. Provisional Application No. 60/088,922, filed on Jun. 11, 1998, the disclosure of which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

1. The Field of the Invention

The present invention relates generally to information displays that utilize color separation prisms. More particularly, the invention relates to a color separation prism assembly and a method for assembling the prism.

2. Present State of the Art

An effective way to achieve precise color separation for many optical applications is by use of dichroic optical interference filters, which are designed to have a sharp transition between transmission and reflection in a precise region of the visible spectrum. Dichroic filters have been used with various types of prisms, along with other optical components. When dichroic filters are utilized on the faces of prisms or prism assemblies, light corresponding to discrete spectral ranges can be re-directed or recombined.

The combination of dichroic filters and prisms is commonly used in color imaging and display systems as a way to separate colors or combine the primary colors into the final image. A compact optical element which accomplishes this purpose is known as a Philips prism. The Philips prism assembly is commonly known, and various uses thereof are described in U.S. Pat. Nos. 2,392,978, 3,659,918, 4,009,941, 4,084,180, and 4,913,528, the disclosures of which are incorporated herein by reference.

Briefly, a Philips prism assembly comprises two triangular prisms and one rectangular prism cemented into an assembly. The two triangular prism elements have an air gap between them. The rectangular prism element is optically cemented on a face thereof to a face of one of the triangular prisms, opposite the air gap bonded face. Dichroic filter coatings are on the faces of the two triangular prisms. When used in an information display system, each prism element has an associated image modulating device aligned with an external facet of each prism element. The image modulating device is usually a cathode ray tube or liquid crystal light valve. The source of light used to form the image can come from the image modulating device, as in the case of a cathode ray tube. Liquid crystal light valves (LCLV) or liquid crystal display (LCD) cells can be used with a Philips prism in a transmission mode using back lit illumination through the LCD cell into the prism.

The LCD cells are more efficient in the reflection mode, as used, for example, in image projection systems disclosed in U.S. Pat. Nos. 5,621,486 and 5,644,432, the disclosures of which are incorporated herein by reference. In this mode, a single illumination source provides white light. A polarizing beam splitter is used to direct one polarization of white light into the facet of the first prism element in the assembly. The prism splits the light into three color channels, typically red, blue, and green, which are transmitted through an exit facet of each prism element to the associated LCD. Each color channel is retroreflected back into the prism by the LCD whereby the polarization of the reflected light is spatially modulated via activation of each particular pixel comprising the LCD image plane. The light reflected from the three LCDs is recombined within the prism assembly and exits the prism through the entrance facet. A color image is formed

when the retroreflected spatially modulated light enters the polarizing beam-splitter, whereby light corresponding to image pixels that caused a 90 degree change in polarization is now transmitted through the polarizing beam splitter, and separated from the unmodulated light. The polarizing beam splitter acts as both a polarizer for light entering the Philips prism and an analyzer for the light exiting the prism to form a spatially modulated image. This image is then projected by an additional lens assembly onto a viewing screen.

Philips prisms are relatively compact optical assemblies for color separation. The angle of incidence for light reflected off the various dichroic coatings is less than 30 degrees, which is not the case for most other color separating prism assemblies. This can be significant, as the performance of dichroic coatings becomes increasingly angle sensitive as the angle of incidence increases.

Prism components and optical coatings are expensive to manufacture. The individual prism elements must be made within sufficiently high tolerances to obtain precise overlap of the recombined images formed at each of the liquid crystal light valves. The optical coatings are also expensive. Antireflection coatings are commonly used on the entrance face of each individual prism, and frequently on any exit face which is not cemented, or optically bonded, to another prism element. In a Philips prism, two of the three prism elements have dichroic coatings applied to their surfaces. Any errors made in prism assembly, whether they result from the assembly method or the tolerance of the individual prism elements, results in defective parts and lost value of coatings and components.

SUMMARY AND OBJECTS OF THE INVENTION

A primary object of the invention is to reduce the cost of prism assemblies used in image display systems, particularly those using Philips prisms. This object is accomplished by an assembly method which corrects for errors in individual prism elements.

Another object of the invention is to provide a color separation prism assembly that corrects for the chromatic aberration of the optical system components.

A further object of the invention is to provide low cost manufacturing methods for the attachment of additional optical components to color separation prisms.

An additional object of the invention is to provide for direct attachment of image modulation devices to the exit facets of a Philips prism.

Another object of the invention is to provide for direct attachment of field lenses to the exit facets of a Philips prism.

To achieve the foregoing objects, and in accordance with the invention as embodied and broadly described herein, a color separation device useful in optical imaging display systems is assembled from three prism elements in an arrangement that provides for air equivalent thickness adjustment for each color. The air equivalent thickness adjustment provides for the correction of deviations in any of the three prisms, as well as providing a method to correct for the chromatic aberration arising from other optical elements in the display system.

The individual prism elements of the color separation device are fabricated in a manner and sequence which results in independent optical path length correction for each color channel, which are defined by the optical coatings within the prism assembly. The air equivalent thickness

within the entire prism assembly for any color channel is varied to meet a predetermined difference, which may be zero. The air equivalent thickness is the physical path length divided by the refractive index. The air equivalent thickness for each color channel is a function of the geometric dimensions of the prism element which separates that color channel and the geometric dimensions of the preceding prism elements within the optical path, along with the refractive index of the prism assembly components.

The physical path within each prism element is varied by adjusting the entrance position of the incident light rays a predictable amount, based on geometric and optical principles. The adjustment is made by assembling the second and third prisms to selectively offset their nominal optical path entrance point from the optical path exit point of the preceding prism. This is accomplished by pre-characterizing each prism element and calculating the distance each prism is translated along its planar interface with the preceding prism to obtain the desired air equivalent thickness.

The color separation device of the invention improves image quality and provides opportunities to lower the display system cost by using low tolerance components and/or plastic optical components normally having a high chromatic aberration.

The method of the invention provides for manufacturing achromatic prisms. Alternatively, the method of the invention provides for manufacturing prisms having a predetermined amount of chromatic aberration to correct for other components in an optical system. The method of assembly corrects for errors in prism dimensions arising from manufacturing steps, providing a prism assembly sufficiently characterized to align and directly attach additional optical components to the prism assembly.

Other features and advantages of the present invention will become apparent from the following description, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to illustrate the manner in which the above-recited and other advantages and objects of the invention are obtained, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered limiting in scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 is a perspective view of a conventional Philips prism assembly;

FIG. 2 is a schematic diagram illustrating the operation of a conventional prism assembly used in a liquid crystal light valve imaging system;

FIG. 3 is a schematic diagram illustrating the ray paths of a conventional prism assembly in which all three prisms have nominal dimensions and are assembled in their nominal positions;

FIG. 4 is a schematic diagram illustrating one embodiment of the present invention in which the first prism is made longer than its nominal dimension and the second and third prisms are assembled with an offset from the nominal position shown in FIG. 3;

FIG. 5 is a schematic diagram illustrating another embodiment of the present invention in which the second prism is made longer than its nominal dimension and the second and third prisms are assembled with an offset from the nominal position shown in FIG. 3;

FIG. 6 is a schematic diagram illustrating the angles and sides of each prism component used to calculate the prism offset distances in the assembly process;

FIGS. 7A and 7B are schematic diagrams for comparing prior art methods of aligning optical components, including the Philips prism used to construct an optical image acquisition or display system; and

FIGS. 8A and 8B illustrate additional embodiments of the invention for attaching optical components directly to a Philips prism in which the alignment procedure is simplified.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a color separation device and a method for assembling the device. The color separation device is assembled from three prisms in an arrangement that provides for air equivalent thickness correction for each color. The air equivalent thickness adjustment provides for the correction of deviations in any of the three prisms, as well as providing a method to correct the chromatic aberration arising from other optical elements in an information display system.

Image quality is improved by the prism assembly of the invention used in information display systems. The method of the invention provides for opportunities to lower the optical system' cost by using low tolerance components and/or plastic optical components such as plastic prism elements which normally have a high chromatic aberration.

Referring to the drawings, like structures are provided with like reference designations. While a Philips prism assembly is used to illustrate the embodiments of the invention, the teachings of the invention are equally applicable to related prism assemblies.

FIG. 1 shows a perspective view of a conventional Philips prism assembly **10**. The prism assembly **10** includes a first triangular prism **12** and a second triangular prism **14**, with a third prism **16** having at least four sides. The triangular prisms **12** and **14** are positioned with respect to each other to provide an air gap **18** at their interface. The second triangular prism **14** and third prism **16** are optically cemented at an interface **20** of these prisms. As indicated in FIG. 1, prism **12** is configured to separate red light (R), prism **14** is configured to separate blue light (B), and prism **16** is configured to receive green light (G).

The light ray paths through prism assembly **10** are shown in FIG. 1. An incident ray i passes into prism **12**, with a portion thereof (e.g. red light) internally reflected and emerging from prism **12** as r_1. The remaining portion of the incident light passes into prism **14**, with a portion thereof (e.g., blue light) internally reflected and emerging from prism **14** as r_2. The remaining portion of the incident ray (e.g., green light) emerges from prism **16** as r_3.

FIG. 2 is a schematic diagram illustrating the operation of prism assembly **10** in a conventional liquid crystal light valve imaging system **100**. A light source **102** provides the illumination in imaging system **100** for forming an image. The light source **102** emits unpolarized light **104** which passes through an optical filter **105** such as a color tuning filter or a notch filter which tunes the wavelength range of the light required for imaging system **100**. The light from optical filter **105** is incident on a polarizing device **106**,

typically a polarizing beam splitter, and light of a selected polarization is reflected into prism assembly **10**. The first triangular prism **12** of prism assembly **10** receives incident light at an entrance facet **22***a* thereof. The prism **12** has a dichroic coating (not shown) on a first exit facet **22***b* which is opposite entrance facet **22***a*. The dichroic coating defines the wavelength range for a first color channel in imaging system **100**. Light reflected by this dichroic coating is totally internally reflected at the surface of facet **22***a* toward a second exit facet **22***c* and is transmitted through facet **22***c*. Light of a first color such as red is thereby selected and directed to a first spatial image modulation device **110** such as an LCD.

The second triangular prism **14** is attached at an entrance facet **24***a* to exit facet **22***b* of prism **12** so as to form a precise air gap **18** therebetween. The prism **14** has a dichroic coating on a first exit facet **24***b* opposite air gap **18**. This dichroic coating defines the wavelength range for a second color channel in imaging system **100**. Light reflected at facet **24***b* exits prism **14** at a second exit facet **24***c* after total internal reflection at facet **24***a*. Light of a second color such as blue is thereby selected and directed to a second spatial image modulation device **112**.

The third prism **16** has an entrance facet **26***a* which is optically bonded or cemented to facet **24***b* of prism **14** and is in contact with the dichroic coating on facet **24***b*. A third color channel is defined by the remaining wavelengths of light which pass into prism **16** from prism **14** that have not been subtracted from the incident beam by the preceding dichroic coatings in the physical path of the light. Light of a third color such as green exits prism **16** at an exit facet **26***b* and is directed to a third spatial image modulation device **114**.

FIG. **3** is a schematic diagram illustrating the light ray paths of prism assembly **10** in which all three prisms **12**, **14**, and **16** have nominal dimensions and are assembled in their nominal positions. The physical paths in these three prisms are indicated in FIG. **3** by the segments of the ray diagram, and must meet the condition: ABCD=ABA'B'C'D'=ABA'B'A"B".

It should be understood that the color separated by each prism element is determined by the optical reflection and transmission characteristics of the associated dichroic coating utilized, and that any of the prism elements can be configured with appropriate dichroic coatings to separate either red, blue or green light. The dichroic coatings on the first two prisms act to separate two wavelength regions. Thus, the color transmitted by the third prism is determined by the first two prisms.

The spatial image modulation devices **110**, **112** and **114** retroreflect each color channel back through prism assembly **10** providing a spatial modulation of the initial polarization state of the light. The modulated image exits prism assembly **10** and passes to polarizing device **106**. The polarizing device **106** selectively transmits only one polarization state to a projection lens **118**, such that the final image, projected onto a viewing screen **120**, is composed by selective activation of individual pixels for each color in the image.

The brightness and color balance of the final projected image is achieved by blending the colors from each of the three separate color images. Precise spatial overlap of each pixel in each of the three image modulation devices is required to properly blend colors and obtain a high-resolution final image. Detrimental aberrations can be inherent in the design and selection of optical components or due to errors in their alignment and assembly. The Philips prism is one potential source of undesirable optical aberration. Thus, a need exists to control and correct for any aberrations in the optical system that defocus the three color channel images.

The present invention provides a technique for reproducibly designing and assembling prism elements to correct for potential aberrations. In addition, the invention provides a way to use a Philips prism to correct for aberrations caused by other optical components. The invention also provides a precise and rapid method for assembling optical components that act in cooperation with each color channel, which eliminates chromatic aberrations caused by improper alignment in the assembly of these components. The methods of the invention are applicable to a broad range of optical systems which utilize Philips prisms. An example of such a system is disclosed in U.S. Pat. No. 5,658,060, which is incorporated herein by reference.

A color separation device according to the invention includes a first prism having a first air equivalent thickness, a second prism having a second air equivalent thickness which is attached to the first prism, and a third prism having a third air equivalent thickness which is attached to the second prism. The second prism is offset from the first prism such that the air equivalent thicknesses for light selected by each of the first and second prisms are substantially equal. In addition, the third prism is offset from the first and second prisms such that the air equivalent thickness of light selected by the third prism is substantially equal to that selected by the first and second prisms.

In a method for assembling the color separation device according to the invention, the physical dimensions of the first and second prisms are measured and the path length in the first prism is calculated. An air equivalent thickness difference between the first and second prisms is then determined. A first physical offset distance is then determined to correct for the air equivalent thickness difference between the first and second prisms such that the air equivalent thickness is the same for the second prism path (through both the first and second prisms) and the first prism path. The first and second prisms are attached at interfacing sides such that the first and second prisms are displaced at their interfacing sides by the first physical offset distance. The physical dimensions of the third prism can be optionally measured, and an air equivalent thickness difference between the first and third prisms is determined. A second physical offset distance is then determined for the third prism to correct for the air equivalent thickness difference between the first and third prisms. The third prism is attached to the second prism such that the second and third prisms are displaced at their interfacing sides by the second physical offset distance.

When the color separation device is used in an optical imaging display system, the first, second, and third prisms can be assembled to provide a predetermined chromatic aberration, which compensates for a chromatic aberration caused by the optical components such as lenses in the display system.

FIG. 4 shows a ray diagram for a prism assembly 30 in accordance with one embodiment of the present invention, in which prism 14 is assembled with an offset with respect to prisms 12 and 16 from the nominal position shown for prism 10 in FIG. 3. The dashed arrowed line in prism 14 represents the physical path for a prism assembly having no deviation from the nominal design in FIG. 3. The dashed line in prism 12 represents the nominal position for the now longer side of prism 12 forming the exit facet adjacent prism 14. The solid segment lines in prism 30 represent the actual physical path caused by the deviations in prisms 12 and 14 utilized to assemble prism 30 in the corrective offset position as shown in FIG. 4. It can be seen that the prisms are offset in one dimension whereby the parallel relationship between connected facets is maintained and the path lengths are equalized such that: (ABCD)new=(ABA'B'C'D')new. The prism 16 is displaced a distance away from the common edge with prism 14 by translating its common facet parallel to the interface. The amount of displacement for prism 16 is calculated such that: (ABCD)new=(ABA'B'A"B") new.

FIG. 5 shows a ray diagram for a prism assembly 40 in accordance with another embodiment of the invention, in which prism 14 is assembled with a different offset with respect to prisms 12 and 16 from the nominal position shown for prism 10 in FIG. 3. The dashed arrowed line in prism 14 represents the physical path for a prism assembly having no deviation from the nominal design in FIG. 3. The dashed line in prism 14 intersecting the arrowed dashed line represents the nominal position for the now longer side of prism 14 forming the exit facet at D'. The solid segment lines in prism 40 represent the actual physical path caused by the deviation in prism 14 utilized to assemble prism 40 in the corrective offset position as shown in FIG. 5.

Since the offsetting of the prism elements in the embodiments of the invention may reduce the image area of a projected image, the prism assembly should be oversized to accommodate for the desired offsets from the nominal design based on the expected deviations from the nominal prism element dimensions.

FIG. 6 defines the physical dimensions which are measured on each prism element, the first physical offset (prism 2 offset), and the second physical offset (assembly height). The offset dimensions are calculated from the physical dimensions to adjust the physical and air equivalent thickness for each color channel independently to the desired or predetermined value. These calculations are based on geometric and optical principles, and are discussed in further detail below in the Examples. The prism assembly ray diagrams of FIGS. 4 and 5 were generated using these calculations.

In the conventional method of manufacturing liquid crystal projection display systems, the liquid crystal image modulation devices must be accurately positioned with respect to the color separation prism so that the projected image is formed by the matched overlap of pixels from each of the three image modulation devices. Conventionally, the image modulation device is attached to the assembled prism with an air gap therebetween. The air gap thickness is manually adjusted to accommodate for variations in optical path length between each of the three color channels arising from chromatic dispersion prism-to-prism variations. Adjustable parameters during the attachment process, in addition to the air gap thickness, are:

1. tilt of the image modulation device front surface about the x-axis;
2. tilt of the image modulation device front surface about the y-axis;
3. rotation of the image modulation device about the z-axis;
4. linear alignment or displacement of the image modulation device along the x-axis; and
5. linear alignment or displacement of the image modulation device along the y-axis.

FIGS. 7A and 7B are schematic diagrams illustrating a prior art method of aligning and assembling an image modulation device 114, such as a liquid crystal light valve, with respect to a prism assembly 10 such as a Philips prism used to construct an optical image acquisition or display system. FIG. 7A illustrates a conventional system in which light is directed by lens 108 into prism assembly 10, and is reflected and transmitted at various wavelengths within prisms 12 and 14 by dichroic coatings 28 and 29. The image modulation device 114 is positioned at a focal distance from exit facet 26*b* of prism 16. The image modulation device must be precisely aligned on an optical test bench by manipulating various spatial parameters, which are depicted in the diagram of FIG. 7B by lines and semicircles with arrows in relation to a three-dimensional (x, y, z) coordinate system. These spatial parameters include: focal distance from the prism exit facet (z-axis linear alignent), linear alignment in the x-axis direction, linear alignment in the y-axis direction, and rotational or tilt alignment about the x, y and z axes.

The above method for aligning an image modulation device is simplified and improved in the following manner when prisms formed by the inventive process are utilized. By reducing or eliminating the air gap thickness adjustment, the aforementioned tilt, rotation, and linear alignment or displacement adjustments can be simplified or reduced to the extent that the image modulation device has a planar front surface and the center and orthogonal axes of the image modulation device can be pre-characterized or controlled.

In the ideal case, physical spacers alone would be sufficient to adjust the air gap thickness and eliminate an adjustment of tilt about the x-axis and y-axis. When the use of physical spacers alone is precluded, a smaller range of air gap adjustment, arising from improvements in the optical path length match within the prism, reduces the time necessary to fully complete the other adjustments which cannot be eliminated.

FIGS. 8A and 8B illustrate additional embodiments of this invention when the image modulation device, or another optical component, has ideal characteristics permitting direct attachment to prism assembly 30.

FIG. 8A illustrates one embodiment in which image modulation device 114 is aligned and optically bonded directly to the exit facet of prism 16 using a substantially uniform optical adhesive layer 124. When the focal distance is short, image modulation device 114 can be directly bonded to the exit facet of prism 16 as shown in FIG. 8A. This provides a cost and performance advantage by eliminating the requirement for antireflection coatings on the exit

facets of the prism elements and on the image modulators. The x and y linear alignments can be automated to correspond to the beam offset characteristic of each prism element and their resulting combination by precisely calculating the beam offset from the corrected alignment positions of the prism elements. Alternatively, at least one image modulation device can be bonded to an exit facet of the corresponding prism element with an air gap between the image modulation device and the exit facet. The air gap distance is controlled by at least one fixed physical spacer connecting a perimeter region of the image modulation device and a perimeter region of the exit facet. When a physical spacer is utilized, at least one antireflection coating is formed on either the exit facet of the prism or on the image modulation device.

FIG. 8B depicts a further embodiment in which a field lens 126 at a first surface thereof is directly bonded to the exit facet of prism 16 using an optical adhesive layer 124. The field lens 126 is provided to correct for lateral chromatic aberration. In an analogous manner to the bonding of the image modulation device shown in FIG. 8A, the present prism assembly method eliminates the need to provide a z-axis linear adjustment which arises from the combined tolerance errors of prisms 12, 14 and 16. A second surface of field lens 126 is opposite image modulation device 114 with an air gap formed therebetween. When field lens 126 is directly bonded to the exit facet of prism 16, at least one physical spacer 128 can be provided to indirectly attach image modulation device 114 to prism 16 resulting in the air gap between field lens 126 and image modulation device 114. The spacer 128 can be a separate component or can be manufactured into field lens 126. In either case, spacer 128 preserves the planar relationship between the exit facet and the front face of image modulation device 114. The thickness of the air gap is controlled by the fixed physical spacer 128 which connects a perimeter region of image modulation device 114 and a perimeter region of the second surface of field lens 126. Preferably, at least one antireflection coating is formed on either the second surface of field lens 126 or on image modulation device 114.

It should be understood that optical components such as image modulators and lenses can be directly or indirectly bonded to the exit facets of the other prism components of prism assembly 30 in the same manner as described above for FIGS. 8A and 8B.

The following examples illustrate various features of the present invention, and are not intended to limit the scope of the present invention.

EXAMPLE 1

This example is described below with reference to FIG. 6. Each of prisms 1, 2 and 3 of the prism assembly in FIG. 6 is characterized by measuring two angles and the length of one side. Prism 2 is offset from prism 1 by using one edge in reference to a zero position, the zero position being one apex of prism 1. The edge of each prism will be referred to by the corresponding angle number, i.e., the edge of prism 1 having angle θ1 will be referred to as edge 1. Edge 3 of prism 1 is used as the reference point for positioning prism 2. Side S1 of prism 1 is used as the reference for positioning side S2 of prism 3. The prism 2 offset distance is measured from edge 3 parallel to side S1 of prism 1 to the intersection of a line perpendicular with side S1 of prism 1. This perpendicular line has an intersection with the corresponding edge 6 of prism 2, establishing the offset with respect to prism 1. The prism offset distances are labeled in FIG. 6.

Prism 1 is characterized by measuring the following two angles and one side: θ1, θ3, and S2. Prism 2 is characterized by measuring the following two angles and one side: θ4, θ6, and S2.

Prism 2 is positioned with respect to prism 1 such that edge 6 is at the prism 2 offset distance and side S1 of prism 2 forms a parallel air gap (e.g., 0.001 inch (20 micron)) with side S2 of prism 1. Prism 2 is bonded to Prism 1 at their edges. This can be accomplished by introducing a liquid UV curable adhesive of relatively high viscosity at the adjoining sides of the prisms and then curing the adhesive before it can wick into the air gap. The air gap can be measured and aligned using shim strips and/or autocollimation optical alignment techniques.

When the prisms are assembled in a machine automated process, a preferred method of producing a repeatable air gap is to utilize an optical adhesive composition that includes a transparent filler material such as uniform spacer beads (e.g., glass micro-spheres or plastic micro-spheres), glass rods, or glass fibers. The physical dimensions of the transparent filler material control the thickness of the adhesive layer bonding the prisms together. A representative adhesive formulation is, for example, Norland 4US- 91 optical cement (Norland Adhesives, North Brunswick, N.J.) filled with 0.5–2.0 weight-% precision glass micro-spheres having a diameter of 20 microns (available from Duke Scientific, Palo Alto, Calif.). This formulation has a sufficiently high viscosity that it can be applied at the perimeter of the active or useful viewing area of prism 1 as a continuous bead. Prism 2 is accurately positioned with respect to prism 1 and pressed into firm contact whereby the air gap is set by the diameter of the micro-spheres. The first and second prisms are held together as the adhesive is cured in a conventional manner, resulting in their permanent attachment.

Prism 3 is characterized by measuring the following two angles and two sides: θ7, θ8, and S2, S4. Prism 3 is positioned with respect to prism 2 whereby the offset is characterized by a predetermined height of the prism assembly, measured from side S2 of prism 3 to side S1 of prism 1. Side S1 of prism 3 is facebonded or optically cemented to side S2 of prism 2. The surfaces of sides S1 and S2 can be face bonded after physical positioning using various types of optical methods that are known to one having ordinary skill in the art.

The calculations for determining the prism offset are provided by a series of formulas linked in a spreadsheet format as shown in Table 1 below. The spreadsheet format provides in column H the equations for calculating a physical path length and in column 1 the equations for calculating a reduced path length (the physical path divided by the refractive index). The reduced path length must be matched at the color channel wavelengths to superimpose the three images at the focal plane.

Tables 2, 3, and 4 below provide examples of the calculations corresponding to the ray diagrams of FIGS. 3, 4, and

5, respectively, where the reduced path length is calculated for each color channel. The physical length in mm is calculated for segments 1–9 (represented in FIG. 6 by the numbers within the triangles). Physical dimensions are input in column E for the respective angle or side in the same row as indicated by column B. The refractive index of the prism material, BK7 glass, is 1.520 at 587.6 nm. The optical adhesive (Norland NOA61) has a refractive index of 1.56. The total path length in prism 1 is calculated as the sum of segments 1, 2 and 3 (e.g., 128 mm in spreadsheet cell in column H, row 15 of Table 1).

In order to equalize the path length for prism 2 (cell having column labeled "measured" and row labeled "green"), the value for the prism 2 offset (cell in column E, row 29) can be modified by the user. This can be done routinely using any spreadsheet software program, for example the "goal seek" or "solver function" provided by the "Excel" program, which is a product of Microsoft Corporation of Redmond, Wash.

In order to equalize the path length for the third prism (cell in column H, row 67), the value of the prism assembly height (cell in column E, row 56) is modified by the user.

It may be necessary to grind surface S4 of prism 3 (e.g., Side (gnd) in column B, row 69 of Table 1), depending on the offset requirements for prism 2 and prism 3, in order to allow a clearance between edge 8 and side S2 of prism 1. Depending on the physical dimensions of the optical components surrounding the prism, it may be necessary to grind and polish surfaces that protrude outside a predetermined boundary. This can be done by one of ordinary skill in the art by drawing the optimum prism configuration, using the dimensions calculated by the methods previously described, and comparing the drawing with an assembly diagram to obtain the required clearances between components. The grinding and polishing operation should be performed prior to assembly of the individual prism elements, after which they should be remeasured according to the methods of the invention.

EXAMPLE 2

In this example, a correction is made for chromatic aberration of the entire optical system such that the air equivalent thicknesses are not equal, but have a predetermined difference. This provides for opportunities to lower the optical system cost by using plastic optical components normally having a high chromatic aberration, while improving the optical system performance, and allowing for simplification of the projection lens. This predetermined difference can be calculated by one having ordinary skill in the art using optical ray tracing software programs, such as "Code V", which is produced by Optical Research Associates of Pasadena, Calif., by providing the appropriate characterization of refractive index dispersion for the materials used in each lens, prism or other optical element which contributes to chromatic aberration in the system.

The assembly method of the prism elements is exactly the same as in Example 1. The spreadsheet format of Table 4 is used to match the reduced path length for each color channel, which is the physical path length divided by the refractive index for the prism glass at the color channel wavelength (corresponding to the center of the passband for the dichroic filter on the same prism). The physical path lengths for ray segments that are common to two or more prisms are divided by the refractive index at the wavelength associated with the prism's color separation channel to arrive at the air equivalent thickness. The same cells in the spreadsheet used in Example 1 that are modified to match physical path lengths are now adjusted to obtain a predetermined difference in reduced path length.

Table 4 provides an example of these calculations wherein the chromatic aberration from optical system components other than the Philips prism are ignored. It can be seen by inspection of the spreadsheet in Table 4 that the first, or blue color channel prism was characterized by a reduced path length at a wavelength of 450 nm for physical path segments 1, 2, and 3 of prism 1. The red color channel was characterized by the sum of reduced path lengths at 650 nm for prisms 1 and 2 and segments 1, 4, 5, 6 and 7. The green color channel was characterized by the sum of reduced path lengths at 550 nm for prisms 1, 2 and 3 and segments 1, 4, 5, 8 and 9. In this case, the target air equivalent thickness for the second and third prisms is dependent on the air equivalent thickness in the first prism, which is calculated by dividing the physical path length in prism 1 by the refractive index of light at 450 nm separated by prism 1.

TABLE 1

	A	B	C	D	E	F	G	H	I
1									
2		BK7 index	1.520	(@587.6 nm)					
3		Adhesive index	1.56	(NOA61)			ray offset	14.040	air equivalent
4								physical path aplimization	thickness
5								physical dims.	for a single wavelength
6			nom.		measured	angle, radians		(mm)	d/n
7									reduced thick.
8	Prism 1	Prism 1					Segment 1:	-H3*TAN(F11)	-H8/C2
9		Angle 1	96.0		95.957	-E9*PIO/180	seg B	-H10/TAN(PO/2-2*F11)	
10		(Angle 2)	56.0		n/a		Segment 2:	-H8/COS(2*F11)	-H10/C2
11		Angle 3	28		27.997	-E11*PIO/180	side 1:	-E13*SIN(F9)/SIN(PIO-F9-F11)	
12									
13		Side 2	40.215		40.1		Segment 3:	-SIN(PIO-F9-F11)*(H11-H9-H3)/(SIN(3*F11+F9-PIO/2)	-H13/C2
14									
15						BLUE	Sum:	-H13 + H10 + H8	-I13 + I10 + I8
16									
17							"x":	-'prism data'1B12/TAN('calculations (2)'IF11)	
18									
19	Air Space								
20		Gap	0.02		0.025		angle in air:	-ASIN(C2*SIN(F11))	
21							Segment 4:	-E20/COS(H20)	-E20/COS(H20)
22							beam displacement:	-H21*SIN(H20-F11)	
23							vertical disp:	-H21*COS(H20-F11)	
24		Wedge angle	0		0	-E24(PIO/180			
25					(.02/30.4)		angle F:	-ASIN(SIN(H20 + F24)/C2)	
26							angle G:	-PIO/2-H25	
27	Prism 2								
28		Prism 2							
29									
30		Prism 2 offset			28.5943	vary this number to match red, blue			
31		Set Height			9.45	with calibration factor included			
32									
33		Angle 4	93.25		93.238	-E22*PIO/180			
34		(Angle 5)	48.5		n/a				
35		Angle 6	38.25		28.267	-E35*PIO/180			
36		Side 2	24.584		24.649				
37							seg. N	-E(30-H3-H22)/SIN(H26)	
38							Segment 5:	-H37*SIN(H35)/SIN(PIO-F35-H26)	-H38/C2
39							seg. M	-H37*SIN(H26)/SIN(PIO-F35-H26)	
40							angle J:	-(PIO-F35-H26)	
41							Segment 6:	-H39*SIN(F35)/SIN(H40-F35)	-H41/C2
42							seg p:	-H41*SIN(PIO-H40)/SIN(F35)	
43							seg q:	-E36*SIN(F33)/SIN(PIO-F35-F33)-H42	
44							angle L:	-H40 + F33 + 2*F35	
45							Segment 7:	-H43(SIN(PIO-F35-F33)/SIN(H44)	-H45/C2
46							Prism 2 path:	-H45 + H41 + H38	-H46/C2
47						RED	sum:	-H46 + H21 + H8	-I46 + I21 + I8
48						BLUE	Sum:	-H13 + H10 + H8	-I15
49									

TABLE 1-continued

	A	B	C	D	E	F	G	H	I
50							Y6=	=TAN(F11)*E30 + E20/COS(F11)	
51							Y4=	=TAN(F11)*E30 + E20/COS(F11) + E36*(SIN(F35-F11-F24))	
52							Y5=	=(TAN(F11)*E30 + E20/COS(F11) + E36*(SIN(F35-F11-F24)))-E31	
53							angle K=	=PIO-F33-(F35-F11-F24)	
54							X2=	=E36(COS(F35-F11-F24)	
55							X3=	=H52/TAN(H53)	
56						1.533	Xset=	=E30 + (E36*COS(F35-F11-F24)) + H55	
57									
58	Prism 3								
59		Assembly hgt(P1–S1 to P3–S2)			39.851	vary this number to match green, blue			
60									
61		Bondline wedge (X°)			0	0			
62		Bond thickness (mm)			0.015		Segment 8:	=E62/COS(PIO/2-H40)	=H26/C3
63		Angle 7	90.0		90	=E63*PIO/180	seg r(hdf):	=H62 + H38 + H8 + H23	
64		Angle 8	81.0		81	=E65*PIO/180	Segment 9:	=E59-H63	=H64/C2
65		(Angle 9)	99.0		99	=E65*PIO/180			
66		(Angle 10)	90.0		90	=E66*PIO/180			
67									
68		S2 Face	19.55						
69		Side (gnd)	21.048						
70						GREEN	sum:	=H8 + H21 + H38 + H62 + H64	=I8 + I21 + I38 + I62 + I64 -I15
71						BLUE	Sum:	=H13 + H10 + H8	

TABLE 2

							Prism 1	Prism 2	Prism 3
	BK7 index	1.520	(@ 587.6 nm)				wavelength, nm	wavelength, nm	wavelength, nm
	Adhesive Inc	1.56	(NOA61)		ray offset	14.040	450	650	550
							1.52532066	1.51852205	1.51452088
						physical dims	d/n	d/n	d/n
		nom.	measured	angle, radians		(mm)	reduced thick.	reduced thick.	reduced thick.
Prism 1	Prism 1				Segment 1:	7.4643	4.8936	4.9285	4.9155
	Angle 1	96.0	95.957	1.67476559	seg B	11.0637			
	(Angle 2)	56.0	n/a		Segment 2:	13.3462	8.7498	8.8122	8.7889
	Angle 3	28	27.997	0.48863983	side 1:	147.4838			
	Side 2	123	123		Segment 3:	101.5127	66.5517	67.0263	66.8496
				BLUE	Sum:	122.3231	80.1950	80.7669	80.5541
	Bevel Compensation				"x":	0.7862			
Air Space									
	Gap	0.02	0.025		angle in air:	0.7945		0.7909	0.7935
					Segment 4:	0.0357		0.0355	0.0356
				beam displacement:		0.0107		0.0106	0.0107
				vertical disp:		0.03403		0.03394	0.03400
	Wedge angle	0	0	0					
			(.02/30.4)		angle F:	0.48863983		0.488639831	0.488639831
					angle G:	1.0821565		1.082156496	1.082156496
Prism 2									
	Prism 2								
	Prism 2 offset		89.078409	vary this number to match red, blue					
	Set Height		9.45	with calibration factor included					
	Angle 4	93.25	93.238	1.62731009					
	(Angle 5)	48.5	n/a						
	Angle 6	38.25	38.267	0.66788514					
	Side 2	75	75						
					seg. N	84.97172			
					Segment 5:	53.4821373		35.31290854	35.21986218
					seg. M	76.2492905			
					angle J:	1.39155101			
					Segment 6:	71.3195186		47.09048225	46.96640303
					seg p:	113.311518			
					seg q:	−13.324237			
					angle L:	1.57152937			
					Segment 7:	−9.97849567		−6.5885	−6.5712
					Prism 2 path:	114.82316		75.8148	75.6151
				RED	sum:	122.3231		80.7789	80.5662
				BLUE	Sum:	122.3231	80.1950		
					Y6=	47.3862			
					Y4=	60.7577			
					Y5=	51.3077			
					angle K=	1.3350			
					X2=	73.7984			
					X3=	12.3255			
				1.533	Xact=	−2.9546			
Prism 3									
	Assembly hgt(P1–S1 to P3-		122.321	vary this number to match green, blue					
	Bondline wedge (X°)		0	0					
	Bond thickness (mm)		0.015		Segment 8:	0.01524424			0.0098
	Angle 7	90.0	90	1.57079633	seg r(hgt):	60.9957	n/a		
	Angle 8	81.0	81	1.41371669	Segment 9:	61.3258		40.3852	
	(Angle 9)	99.0	99	1.72787596					
	(Angle 10)	90.0	90	1.57079633					
	S2 Face	19.55							
	Side (gnd)	21.048							
				GREEN	sum:	122.3231			80.5659
				BLUE	Sum:	122.3231	80.1950		
							blue	red	green
							80.1950	80.7789	80.5659

TABLE 3

						Prism 1	Prism 2	Prism 3
BK7 index	1.520	(@ 587.6 nm)				wavelength, nm	wavelength, nm	wavelength, nm
Adhesive Inc	1.56	(NOA61)		ray offset	14.040	450	650	550
						1.52532066	1.51852205	1.51452088
					physical dims	d/n	d/n	d/n

TABLE 3-continued

							Prism 1	Prism 2	Prism 3
		nom.	measured	angle, radians		(mm)	reduced thick.	reduced thick.	reduced thick.
Prism 1	Prism 1				Segment 1:	7.4643	4.8936	4.9285	4.9155
	Angle 1	96.0	95.957	1.647476559	seg B	11.0637			
	(Angle 2)	56.0	n/a		Segment 2:	13.3462	8.7498	8.8122	8.7889
	Angle 3	28	27.997	0.48863983	side 1:	153.4791			
	Side 2	123	128		Segment 3:	106.4857	69.8120	70.3098	70.1245
				BLUE	Sum:	127.2961	83.4553	84.0504	83.8290
	Bevel Compensation				"x":	0.7862			
Air Space									
	Gap	0.02	0.025		angle in air:	0.7945		0.7909	0.7935
					Segment 4:	0.0357		0.0355	0.0356
				beam displacement:		0.0107		0.0106	0.0107
				vertical disp:		0.03403		0.03394	0.03400
	Wedge angle	0	0	0					
			(.02/30.4)		angle F:	0.48863983		0.488639831	0.488639831
					angle G:	1.0821565		1.082156496	1.082156496
Prism 2									
	Prism 2								
	Prism 2 offset		98.419564	vary this number to match red, blue					
	Set Height		9.45	with calibration factor included					
	Angle 4	93.25	93.238	1.62731009					
	(Angle 5)	48.5	n/a						
	Angle 6	38.25	38.267	0.66788514					
	Side 2	75	75						
					seg. N	95.5509373			
					Segment 5:	60.1408133		39.70946462	39.60483372
					seg. M	85.7425408			
					angle J:	1.39155101			
					Segment 6:	80.1989986		52.95337926	52.81385184
					seg p:	127.41912			
					seg q:	−27.4318385			
					angle L:	1.57152937			
					Segment 7:	−20.5436516		−13.5645	−13.5287
					Prism 2 path:	119.79616		79.0984	78.8900
				RED	sum:	127.2961		84.0624	83.8411
				BLUE	Sum:	127.2961	83.4553		
					Y6=	52.3523			
					Y4=	65.7238			
					Y5=	56.2738			
					angle K=	1.3350			
					X2=	73.7984			
					X3=	13.5185			
				1.533	Xset=	−11.1027			
Prism 3									
	Assembly hgt(P1-S1 to P3-		127.294	vary this number to match green, blue					
	Bondline wedge (X°)		0	0					
	Bond thickness (mm)		0.015		Segment 8:	0.01524424			0.0098
	Angle 7	90.0	90	1.57079633	seg r(hgt):	67.6543	n/a		
	Angle 8	81.0	81	1.41371669	Segment 9:	59.6401			39.2751
	(Angle 9)	99.0	99	1.72787596					
	(Angle 10)	90.0	90	1.57079633					
	S2 Face	19.55							
	Side (gnd)	21.048							
				GREEN	sum:	127.2961			83.8408
				BLUE	Sum:	127.2961	83.4553		
							blue	red	green
							83.4553	84.0624	83.8408

TABLE 4

							Prism 1	Prism 2	Prism 3
	BK7 index	1.520	(@ 587.6 nm)				wavelength, nm	wavelength, nm	wavelength, nm
	Adhesive Inc	1.56	(NOA61)		ray offset	14.040	450	650	550
							1.52532066	1.51852205	1.51452088
						physical dims	d/n	d/n	d/n
		nom.	measured	angle, radians		(mm)	reduced thick.	reduced thick.	reduced thick.
Prism 1	Prism 1				Segment 1:	7.4643	4.8936	4.9285	4.9155
	Angle 1	96.0	95.957	1.67476559	seg B	11.0637			
	(Angle 2)	56.0	n/a		Segment 2:	13.3462	8.7498	8.8122	8.7889

TABLE 4-continued

							Prism 1	Prism 2	Prism 3
	Angle 3	28	27.997	0.48863983	side 1:	147.4838			
	Side 2	123	123		Segment 3:	101.5127	66.5517	67.0263	66.8496
				BLUE	Sum:	122.3231	80.1950	80.7669	80.5541
	Bevel Compensation				"x":	0.7862			
Air Space									
	Gap	0.02	0.025		angle in air:	0.7945		0.7909	0.7935
					Segment 4:	0.0357		0.0355	0.0356
				beam displacement:		0.0107		0.0106	0.0107
				vertical disp:		0.03403		0.03394	0.03400
	Wedge angle	0	0	0					
			(.02/30.4)		angle F:	0.48863983		0.488639831	0.488639831
					angle G:	1.0821565		1.082156496	1.082156496
Prism 2									
	Prism 2								
	Prism 2 offset		78.040565	vary this number to match red, blue					
	Set Height		9.45	with calibration factor included					
	Angle 4	93.25	93.238	1.62731009					
	(Angle 5)	48.5	n/a						
	Angle 6	38.25	38.267	0.66788514					
	Side 2	75	75						
					seg. N	72.4709363			
					Segment 5:	45.6140062		30.11777971	30.03842205
					seg. M	65.0317243			
					angle J:	1.39155101			
					Segment 6:	60.8272057		40.16267223	40.05684717
					seg p:	96.6414685			
					seg q:	10.0116313			
					angle L:	1.57152937			
					Segment 7:	7.49769159		4.9505	4.9375
					Prism 2 path:	113.938904		75.2310	75.0328
				RED	sum:	121.4388		80.1950	79.9839
				BLUE	Sum:	122.3231	80.1950		
					Y6–	41.5180			
					Y4–	55.7809			
					YS–	46.3309			
					angle K–	1.3350			
					X2–	78.7183			
					X3–	11.1299			
				1.533	Xset–	11.8076			
Prism 3									
	Assembly hgt(P1–S1 to P3-		121.758	vary this number to match green, blue					
	Bondline wedge (X°)		0	0					
	Bond thickness (mm)		0.015		Segment 8:	0.01524424			0.0098
	Angle 7	90.0	90	1.57079633	seg r(hgt):	53.1275	n/a		
	Angle 8	81.0	81	1.41371669	Segment 9:	68.6306			45.1957
	(Angle 9)	99.0	99	1.72787596					
	(Angle 10)	90.0	90	1.57079633					
	S2 Face	19.55							
	Side (gnd)	21.048							
				GREEN	sum:	121.7598			80.1950
				BLUE	Sum:	122.3231	80.1950		
							blue	red	green
							80.1950	80.1950	80.1950

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed and desired to be secured by United States Letters Patent is:

1. A color separation device comprising:

a first prism having a first air equivalent thickness;

a second prism having a second air equivalent thickness and attached to the first prism;

a third prism having a third air equivalent thickness and attached to the second prism; wherein the second prism is offset a predetermined distance from a nominal position with respect to the first prism to correct for an air equivalent thickness difference between the first and second prisms in the nominal position such that the air equivalent thicknesses for light selected by each of the first, second, and third prisms are substantially equal.

2. The color separation device of claim 1, wherein the first and second prisms are triangular and the third prism is rectangular.

3. The color separation device of claim 1, wherein the third prism is offset a predetermined distance from a nominal position with respect to the second prism to correct for an air equivalent thickness difference between the first and third prisms such that the air equivalent thicknesses for light selected by each of the first, second, and third prisms are substantially equal.

4. The color separation device of claim 1, wherein the first, second, and third prisms are composed of a plastic material.

5. The color separation device of claim 1, further comprising an air gap formed at the interface of the first and second prisms.

6. The color separation device of claim 1, further comprising a first dichroic coating on an exit facet of the first prism and a second dichroic coating on an exit facet of the second prism.

7. A method for assembling a color separation device, comprising the steps of:

measuring the physical dimensions of a first prism;

measuring the physical dimensions of a second prism;

determining an air equivalent thickness difference between the first and second prisms at a nominal position;

determining a first physical offset distance to correct for the air equivalent thickness difference between the first and second prisms at the nominal position;

attaching the first prism to the second prism at interfacing sides such that the first and second prisms are displaced from the nominal position at their interfacing sides by the first physical offset distance;

determining an air equivalent thickness difference between the first and third prisms;

determining a second physical offset distance to correct for the air equivalent thickness difference between the first and third prisms; and

attaching the third prism to the second prism at interfacing sides such that the second and third prisms are displaced at their interfacing sides by the second physical offset distance.

8. The method of claim 7, wherein the first and second prisms are triangular and the third prism is rectangular.

9. The method of claim 7, wherein the first, second, and third prisms are composed of a plastic material.

10. The method of claim 7, wherein the first prism is attached to the second prism such that an air gap is formed between the interfacing sides of the first and second prisms.

11. The method of claim 7, further comprising the steps of forming a first dichroic coating on an exit facet of the first prism, and forming a second dichroic coating on an exit facet of the second prism.

12. An optical imaging display system, comprising:

one or more image modulating devices;

one or more image projection lenses; and

a color separation prism assembly in optical communication with the image modulating devices and lenses, the prism assembly comprising:

a first prism having a first air equivalent thickness;

a second prism having a second air equivalent thickness and attached to the first prism; and

a third prism having a third air equivalent thickness and attached to the second prism;

wherein the second prism is offset from the first prism such that the air equivalent thicknesses for light selected by each of the first, second, and third prisms are substantially equal.

13. The display system of claim 12, wherein the first and second prisms are triangular and the third prism is rectangular.

14. The display of claim 12, wherein the third prism is offset from the second prism such that the air equivalent thicknesses for light selected by each of the first, second, and third prisms are substantially equal.

15. The display system of claim 12, wherein each of the first, second, and third prisms are in optical communication with a corresponding image modulation device.

16. The display system of claim 15, wherein each image modulation device is attached to an exit facet of each of the first, second, and third prisms.

17. The display system of claim 15, further comprising a field lens attached to an exit facet of each of the first, second, and third prisms.

18. The display system of claim 17, wherein each image modulation device is attached to the field lens on each of the first, second, and third prisms.

19. An optical imaging display system, comprising:

one or more image modulating devices;

one or more image projection lenses;

a color separation prism assembly in optical communication with the image modulating devices and lenses, the prism assembly comprising:

a first prism having a first air equivalent thickness;

a second prism having a second air equivalent thickness and attached to the first prism; and

a third prism having a third air equivalent thickness and attached to the second prism;

wherein the first, second, and third prisms are assembled to provide a predetermined chromatic aberration which compensates for a chromatic aberration caused by one or more optical components in the display system.

20. The display system of claim 19, wherein the first and second prisms are triangular and the third prism is rectangular.

21. The display system of claim 19, wherein at least two of the first, second, or third prisms are directly bonded together with a substantially uniform optical adhesive layer therebetween, the optical adhesive comprising a transparent filler material whereby the physical dimensions of the transparent filler material control the thickness of the optical adhesive layer.

22. The display system of claim 21, wherein the transparent filler material is selected from the group consisting of glass micro-spheres, plastic micro-spheres, glass rods, and glass fibers.

23. The display system of claim 19, wherein each of the first, second, and third prisms are in optical communication with a corresponding image modulation device.

24. The display system of claim 23, wherein each image modulation device is attached to an exit facet of each of the first, second, and third prisms.

25. The display system of claim 24, wherein at least one image modulation device is directly bonded with a substantially uniform optical adhesive layer to the exit facet of the corresponding prism.

26. The display system of claim 24, wherein at least one image modulation device is bonded to an exit facet of the corresponding prism element with an air gap between the image modulation device and the exit facet, the air gap controlled by at least one fixed physical spacer connecting a perimeter region of the image modulation device and a perimeter region of the exit facet.

27. The display system of claim 26, further comprising at least one antireflection coating on either the exit facet or on the image modulation device.

28. The display system of claim 23, further comprising a field lens attached to an exit facet of each of the first, second, and third prisms.

29. The display system of claim 28, wherein each image modulation device is attached to the field lens on each of the first, second, and third prisms.

30. The display system of claim 23, further comprising at least one field lens having a first surface opposite an exit facet of at least one of the prisms and a second surface

D. U.S. Patent No. 6,250,762 (Kuijper)

US006250762B1

(12) United States Patent
Kuijper

(10) Patent No.: **US 6,250,762 B1**
(45) Date of Patent: **Jun. 26, 2001**

(54) **IMAGE PROJECTION SYSTEM**

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(73) Assignee: **U.S. Philips Corporation**, New York, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(86) PCT No.: **PCT/IB99/01224**

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(87) PCT Pub. No.: **WO00/02087**

PCT Pub. Date: **Jan. 13, 2000**

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(51) **Int. Cl.**^{7} **G03B 21/121**

(52) **U.S. Cl.** **353/20**; 353/81

(58) **Field of Search** 353/20, 31, 34, 353/37, 81; 349/5, 494, 499, 8, 9

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,374,968 *	12/1994	Haven et al.	353/31
5,986,815 *	11/1999	Bryars	359/634
6,082,861 *	7/2000	Dove et al.	353/20
6,089,718 *	7/2000	Hashizume	353/31

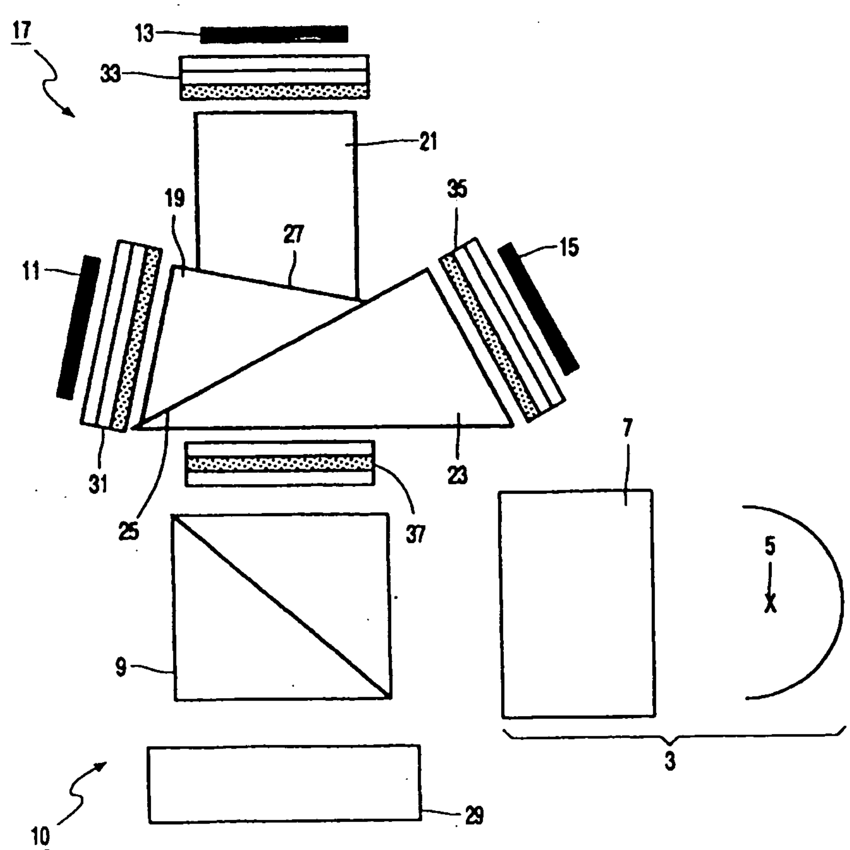
* cited by examiner

Primary Examiner—William Dowling

(57) **ABSTRACT**

The present invention relates to an image projection system (1) comprising an illumination system (3) and a modulation system comprising three image display panels (11, 13 and 15) of the relative type. The light beam coming from the illumination system (3) is color-separated and, after modulation by the image display panels, color-recombined by a color-separating and a color-recombining element (17). At least between the element (17) and the display panels (11, 13 and 15) is arranged a polarization-compensating element (31, 33, 35).

5 Claims, 2 Drawing Sheets



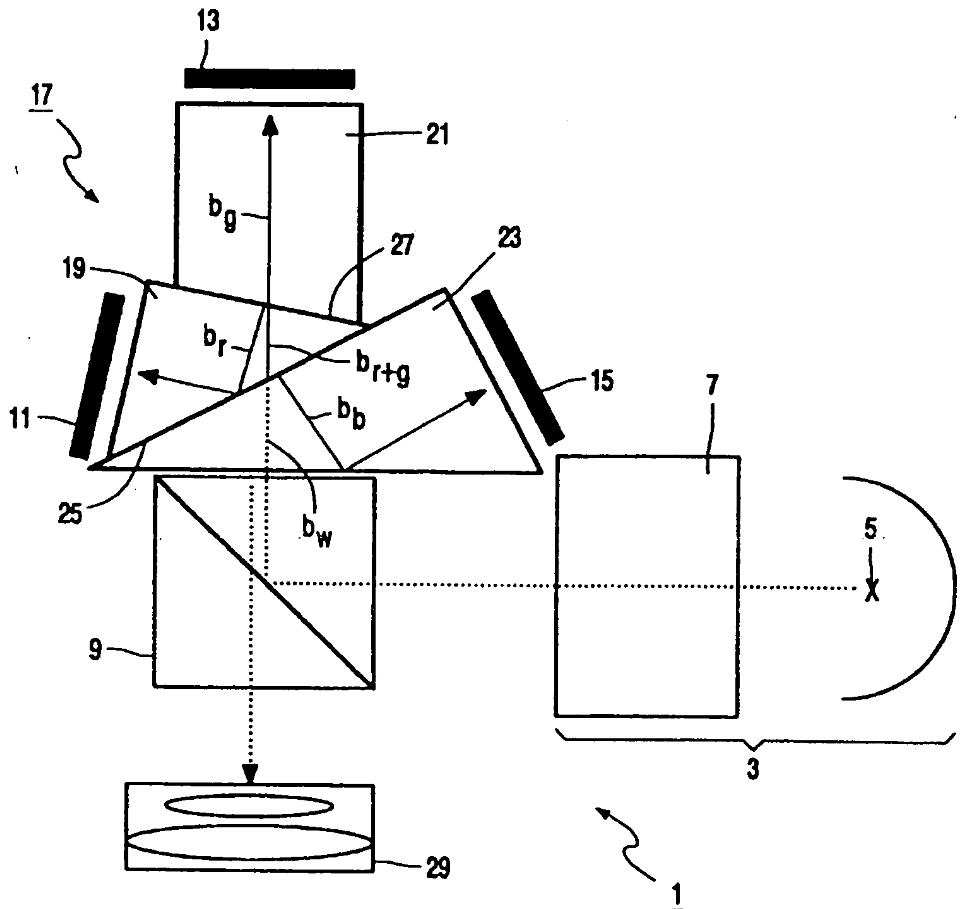
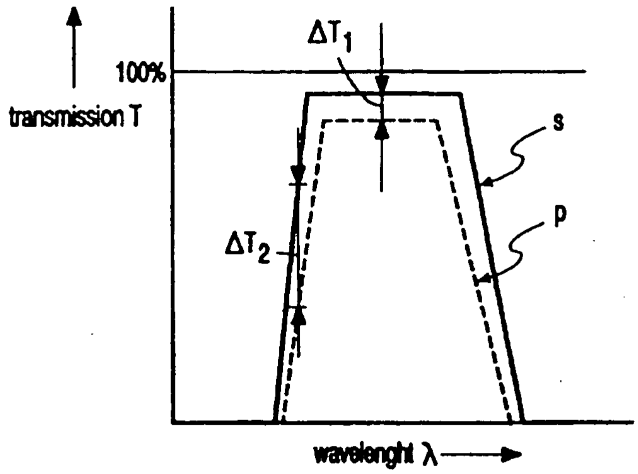
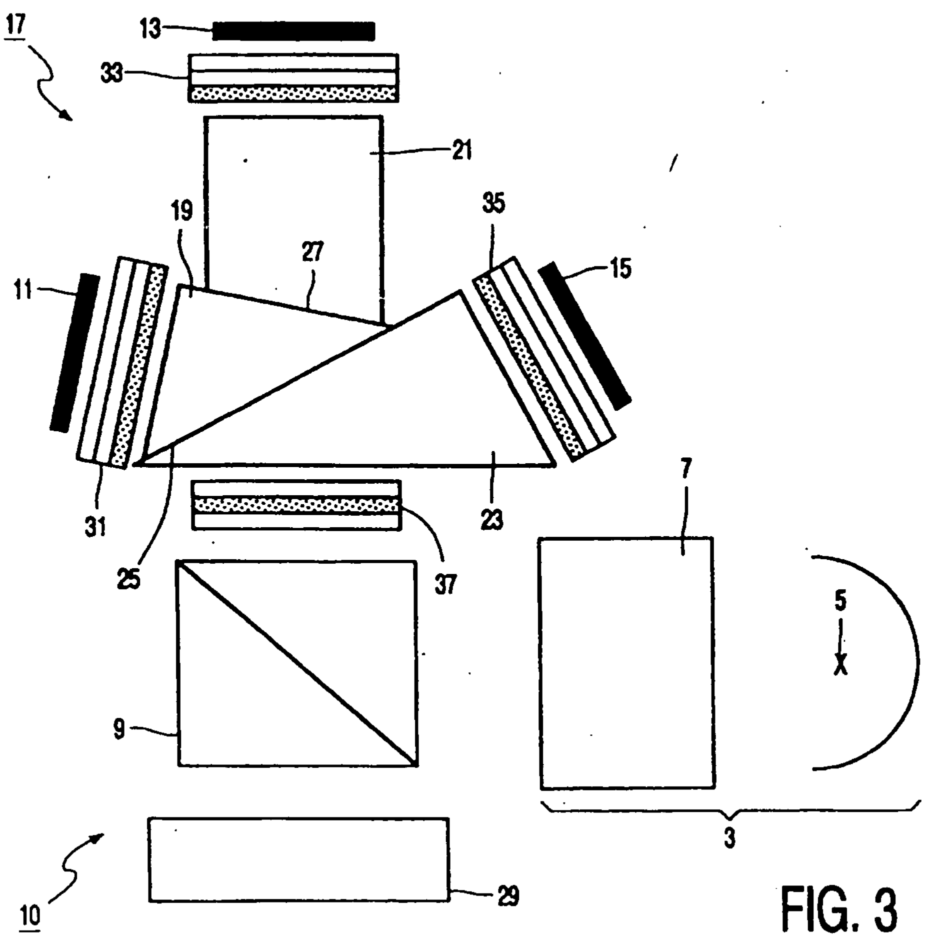


FIG. 1



transmission T
100%
ΔT1
ΔT2
s
p
wavelenght λ

FIG. 2



17
13
33
21
19
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35
11
15
31
25
23
37
7
5
9
3
10
29

FIG. 3

IMAGE PROJECTION SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to an image projection system comprising an illumination system, a modulation system having at least two reflecting image display panels of the non-diffusing type for modulating light generated by the illumination system in conformity with image information to be projected, and a projection lens system. The image projection system includes an element having a color-separating as well as a color-recombining effect, and a polarizing beam splitter which is situated between the illumination system and the element and between the element and the projection lens system.

A reflective image display panel of the non-diffusing type is understood to mean a reflective liquid crystalline image display panel of the non-diffusing type or a DMD or the like.

An image projection system comprising two or three reflective image display panels may be given a very compact construction if the color separation and the color recombination are effected by one and the same optical system. The optical system may comprise, for example, a polarizing beam splitter. Since the other optical elements of such an optical system are situated between the reflective display panels and the polarizing beam splitter, it is undesirable that a change of polarization would be effected by the color-separating and color-recombining element. However, this is the case in practice, so that the ultimate image has a too low contrast and strong color deviations for all luminance levels between white and black. This is caused by the polarization-dependent transmission of the color-separating faces of the color-separating element and the geometrical decomposition of the polarization vector on all oblique faces due to non-perpendicular incidence. Each color channel causes a specific change of polarization as a function of the wavelength and the direction of propagation through the color-separating element. In addition to polarization changes of the light, light having a given direction of polarization may be reflected in an unwanted direction, In addition to strong color shifts in a color channel, this also causes unwanted optical crosstalk when light having a certain wavelength reaches a reflective display panel which is meant to modulate light of another wavelength.

The cause of the above-mentioned polarization effects is found in the relatively large angle of incidence on the color-separating faces of the color-separating element. Dependent on the element used, this angle of incidence may be between 10–20° and 45°. For a large angle of incidence, it is difficult to have an equal transmission characteristic of a color-separating coating for both s-polarized and p-polarized light. The smaller the angle of incidence, the smaller the above-mentioned problem will be. For small angles of incidence, the difference of transmission between p and s-polarized light can be minimized more easily. But also in this case, for example for a plumbicon prism, there is still a change of polarization.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an image projection system in which the above-mentioned drawbacks are obviated.

To that end, the image projection system includes at least one polarization-compensating element is situated between the element and the image display panels.

After minimizing the differences between the transmission for s and p-polarized light in the desired wavelength

range and for the desired viewing angles, by making use of a color-separating element suitable for this purpose, the remaining rotation of polarization induced by the color-separating element is reduced by means of polarization-compensating elements.

A preferred embodiment of the image projection system according to the present invention is characterized in that at least one polarization-compensating element is situated between the polarizing beam splitter and the element.

The solution to the above-mentioned problem is thus found in the addition of polarization-compensating elements. Said elements may be provided to the entrance face of the color-separating element and/or to one or more of the three exit faces of the element. "To the entrance face" is understood to be between the polarizing beam splitter and the color-separating element and "to the exit faces" is understood to be between the color-separating element and the display panels. Direct optical contact is not required.

A further embodiment of the image projection system according to the present invention is characterized in that the polarization-compensating element is a birefringent element.

A very suitable compensating element may comprise a birefringent element or a combination of birefringent elements. A birefringent element or a combination of birefringent elements ensures that a change of polarization by the color-separating element is substantially eliminated within the wavelength range for a plurality of propagation directions.

A further embodiment of the image projection system according to the present invention is characterized in that the birefringent element has a biaxial symmetry.

When the color-separating element has a viewing angle-dependent behavior which is different for the horizontal viewing directions with respect to the vertical viewing directions, the polarization-compensating element is preferably a birefringent element having a biaxial symmetry.

A further embodiment of the image projection system according to the present invention is characterized in that the birefringent element has a tilted optical axis.

If there is a difference between the positive and negative viewing directions, an element having a tilted optical axis is advantageous.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an image projection system comprising a polarizing beam splitter and one combined color-separating and color-recombining element, according to the prior art;

FIG. 2 illustrates the difference in transmission for p-polarized and s-polarized light; and

FIG. 3 shows an image projection system comprising a polarizing beam splitter and one combined color-separating and color-recombining element, according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows an image projection system 1 comprising an illumination system 3 having a light source 5 and illumination optics 7. The illumination optics 7 may comprise, for example, a condenser lens and an integrator system (not shown).

In case that unpolarized light coming from the illumination system 3 is incident on a polarizing beam splitter 9, approximately half of said light is sent to the modulation system comprising, in this Figure, three reflective light valves 11, 13 and 15, one for each primary color. The other half of the light beam coming from the illumination system 3 will be lost.

In case that the illumination optics 7 comprise a polarization converting system (PCS), the light beam from the light source will have been converted into a light beam having substantially the same polarization direction. In that case, the polarizing beam splitter acts as a folding element. The more perfect the PCS has converted the unpolarized light into polarized light, the less light will be lost at the polarizing beam splitter.

Consequently, the light beam bent by the polarizing beam splitter is incident on a color-separating element 17. Said element 17, of which the shown embodiment is also called in plumbicon prism, comprises three prisms 19, 21 and 23. At a first interface 25, the white light beam b_w from the illumination system is split up is a blue sub-beam b_b and a red-green sub-beam b_{r-g}. At a second interface 27, the red-green sub-beam b_{r-g} is split up in a red sub-beam b_r and a green sub-beam b_g. Each of the sub-beams b_r, b_b and b_g is incident on a respective reflective light valve 11, 13, 15 which is suited to modulate the light incident thereon.

After modulation by the light valves 11, 13 and 15, the modulated sub-beams are recombined by the element 17. Said element 17 now performs the function of a color-recombining element. In case the light valves are polarization modulating light valves, the parts of the combined modulated beams which have to result in bright parts in the image are subsequently transmitted to the projection lens system 29. The polarizing beam splitter then acts as an analyzing polarizer.

One of the problems in an image projection system as described above is, that due to an oblique incidence of the beams to be color-separated or color-recombined on the interfaces of the element 17, the polarization directions will change because the transmission of the color-separating and recombining surfaces is polarization dependent. This difference and variation in transmission results in a low contrast and color deviations in the image.

FIG. 2 illustrates, for a color-separating or color-recombining interface, the transmission as a function of wavelength for s-polarized and p-polarized light. In a certain wavelength range, the difference in transmission is relatively small ($\Delta T1$), while at the edges of said range the difference becomes much larger ($\Delta T2$).

The present invention overcomes said drawbacks by providing at least one polarization-compensating element 31, 33, 35 between the element 17 and the light valves 11, 13, 15.

FIG. 3 shows an embodiment of an image projection system 10 according to the present invention.

Contrast and color balance of the image can be further improved by providing a polarization-compensation element 37 between the color-recombining element 17 and the polarization beam splitter 9.

A preferred embodiment of such polarization-compensating elements 31, 33, 35 and 37 is a birefringent element or a combination of birefringent elements.

The sensitivity of the color-separating and recombining element with respect to the viewing angle may vary for the vertical and the horizontal viewing direction. In that case, the birefringent element preferably has a biaxial symmetry. If there is moreover a difference between the positive and the negative viewing directions, the birefringent element preferably has a tilted optical axis.

Birefringent elements as mentioned above are commercially available from a.o. Nitto Denko and Fuji Film.

What is claimed is:

1. An image projection system comprising an illumination system, a modulation system having at least two reflecting image display panels of the non-diffusing type for modulating light generated by the illumination system in conformity with image information to be projected, and a projection lens system, the image projection system comprising an element having a color-separating as well as a color-recombining effect, and a polarizing beam splitter which is situated between the illumination system and the element and between the element and the projection lens system, wherein at least one polarization-compensator is situated between the element and the image display panels and a further polarization-compensator is situated between the element and the polarizing beam splitter, and wherein said at least one polarization-compensator and said further polarization-compensator are configured to compensate for a change of polarization of light leaving the element.

2. An image projection system as claimed in claim 1, wherein the polarization-compensator is a birefringent element.

3. An image projection system as claimed in claim 2, wherein the birefringent element has a biaxial symmetry.

4. An image projection system as claimed in claim 2, wherein the birefringent element has a tilted optical axis.

5. A projection apparatus comprising:

a light source which provides input light;

a polarizing beam splitter which bends a portion of said input light to for a bent light;

a prism assembly which separates color components of said bent light;

reflective imagers which receive said color components to form color image lights, said prism assembly combining said color image lights to form an image light, and said polarizing beam splitter providing said image light to a projection lens;

polarization-compensators located between said reflective imagers and said prism assembly, said polarization-compensators being configured to compensate for a change of polarization of said color components leaving said prism assembly; and

a further polarization-compensator located between said prism assembly and said polarizing beam splitter, said further polarization-compensator being configured to compensate for a change of polarization of said image light leaving said prism assembly.

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E. U.S. Patent No. 6,390,626 (Knox)

US006390626B2

(12) **United States Patent**
Knox

(10) **Patent No.:** **US 6,390,626 B2**
(45) **Date of Patent:** ***May 21, 2002**

(54) **IMAGE PROJECTION SYSTEM ENGINE ASSEMBLY**

(75) Inventor: **Richard M. Knox**, Houston, TX (US)

(73) Assignee: **Duke University**, Durham, NC (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/730,818**

(22) Filed: **Oct. 17, 1996**

(51) **Int. Cl.**[7] **G03B 21/14**

(52) **U.S. Cl.** **353/20**; 353/31; 353/84; 349/9

(58) **Field of Search** 353/20, 31, 33, 353/34, 37, 84; 349/9, 8; 348/742, 743

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,652,163	A	3/1972	Borkowski et al.
4,425,028	A	1/1984	Gagnon et al.
4,526,442	A	7/1985	Betensky et al.
4,544,237	A	10/1985	Gagnon
4,961,642	A	10/1990	Ogino
4,969,732	A	11/1990	Wright et al.
5,130,850	A	7/1992	Toide
5,193,015	A	3/1993	Shanks
5,218,480	A	6/1993	Moskovich
5,223,869	A	6/1993	Yanagi
5,237,641	A	8/1993	Jacobson et al.
5,243,459	A	9/1993	Winston et al.
RE34,492	E	12/1993	Roberts
5,289,312	A	2/1994	Hashimoto et al.
5,303,322	A	4/1994	Winston et al.
5,323,414	A	6/1994	Baird et al.
5,333,072	A	7/1994	Willett
5,337,106	A	8/1994	Jutamulia et al.
5,371,628	A	12/1994	Shimoda et al.

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

EP	0463816 A2		1/1992	.... G02F/1/137
EP	0 488 590 A1		6/1992	
EP	0783133 A1		7/1997	.... G03B/21/60
FR	2673006		2/1992	.... G02F/1/133
JP	61013885		1/1986	.... H04N/5/74
JP	0211418	*	8/1990	.... 353/20
JP	03063690		3/1991	.... G09F/9/00
JP	03187696		8/1991	.... H04N/9/31
JP	3-243932		10/1991	
WO	WO 96/37806		11/1996	
WO	WO 97/10490		3/1997	

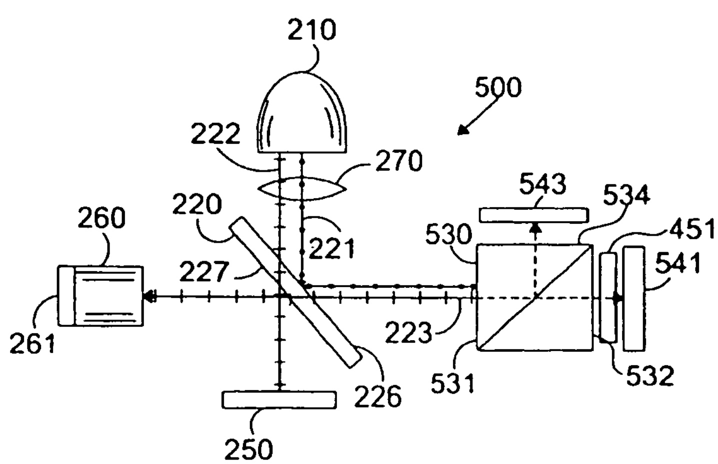
* cited by examiner

Primary Examiner—William Dowling
(74) *Attorney, Agent, or Firm*—Fleshner & Kim, LLP

(57) **ABSTRACT**

A light projection engine uses a wide angle reflecting polarizer material (preferably 3M DBEF brand double brightness enhancement filter) as a polarizing beamsplitter to direct polarized light to beam splitter/combiner (such as an X-cube dichroic reflector). The beam splitter/combiner then splits the directed polarized light into separate reflective LCD panels acting as light valves. The LCD panels alter the polarity of the incident light from 0 degrees up to 90 degrees to control which light is passes from the wide angle reflecting polarizer back towards the light source and which light has the necessary polarization change to allow it to pass from the wide angle reflecting polarizer to the lens system. After reflecting off of the LCD panels, the light goes back through the X-cube dichroic reflector, where it is recombined. The recombined light which is of a first polarity is transmitted from the reflecting polarizer to the lens system, while the recombined light which is of a second polarity is transmitted to the light source. The LCDs are preferably analog polarizing LCDs.

42 Claims, 10 Drawing Sheets



U.S. PATENT DOCUMENTS

5,384,607	A		1/1995	Morris et al.	
5,389,982	A	*	2/1995	Lee	353/20
5,404,076	A	*	4/1995	Dolan et al.	313/572
5,424,869	A		6/1995	Nanjo	
5,453,859	A	*	9/1995	Sannohe et al.	353/20
5,463,433	A	*	10/1995	Koo	353/84
5,467,146	A	*	11/1995	Huang et al.	348/743
5,467,154	A		11/1995	Gale et al.	353/119
5,517,340	A	*	5/1996	Doany et al.	359/41
5,528,720	A		6/1996	Winston et al.	
5,539,579	A		7/1996	Miyatake et al.	
5,552,938	A		9/1996	Sugawara	
5,557,343	A		9/1996	Yamagishi	
5,557,478	A		9/1996	Winston et al.	
5,573,324	A	*	11/1996	DeVaan	353/77
5,594,591	A		1/1997	Yamamoto et al.	
5,594,830	A		1/1997	Winston et al.	
5,597,222	A		1/1997	Doany et al.	
5,604,607	A		2/1997	Mirzaoff	
5,610,768	A		3/1997	Winston	
5,621,486	A	*	4/1997	Doany et al.	353/34
5,653,520	A		8/1997	Kato	
5,692,820	A		12/1997	Gale et al.	353/77
5,706,063	A	*	1/1998	Hong	349/9
5,738,426	A	*	4/1998	Daijogo et al.	353/20
5,800,032	A		9/1998	Uchiyama et al.	
5,805,326	A		9/1998	Snow et al.	
5,833,360	A	*	11/1998	Knox et al.	362/293
5,867,239	A	*	2/1999	Sahouani et al.	349/117
5,868,480	A	*	2/1999	Zeinali	353/31
5,890,786	A	*	4/1999	Kurematsu	353/20
5,900,987	A		5/1999	Kreitzer	
5,912,762	A	*	6/1999	Li et al.	359/352
5,923,116	A		7/1999	Mercer et al.	
5,940,149	A	*	8/1999	Vanderwerf	349/5
5,949,589	A		9/1999	Nakazawa	
5,969,874	A		10/1999	Moskovich	
5,975,703	A	*	11/1999	Holman et al.	353/20
6,005,332	A		12/1999	Mercer	
6,172,813	B1	*	1/2001	Tadic-Galeb et al.	359/618
6,181,386	B1	*	1/2001	Knox	348/788
6,220,713	B1	*	4/2001	Tadic-Galeb et al.	353/77

FIG. 1

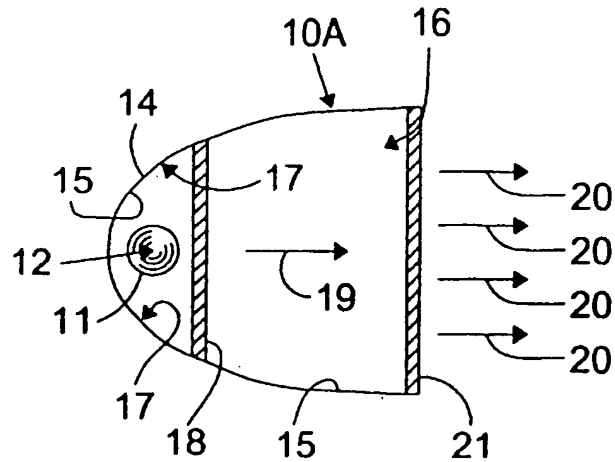


FIG. 1A

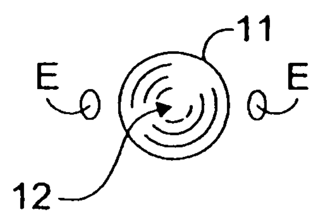


FIG. 2

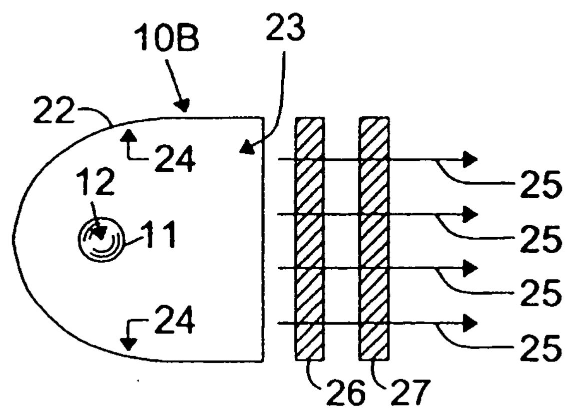


FIG. 3

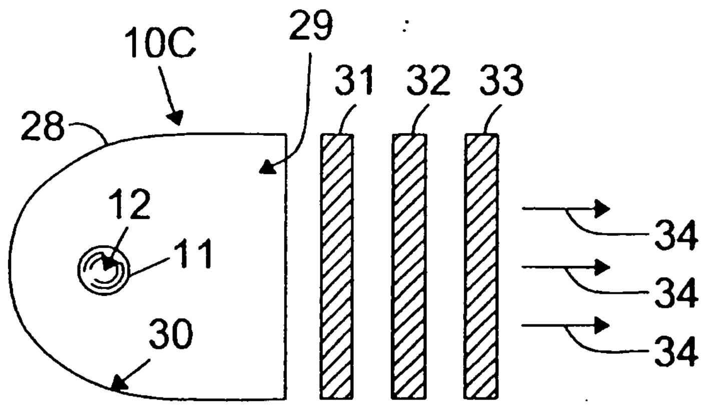


FIG. 6

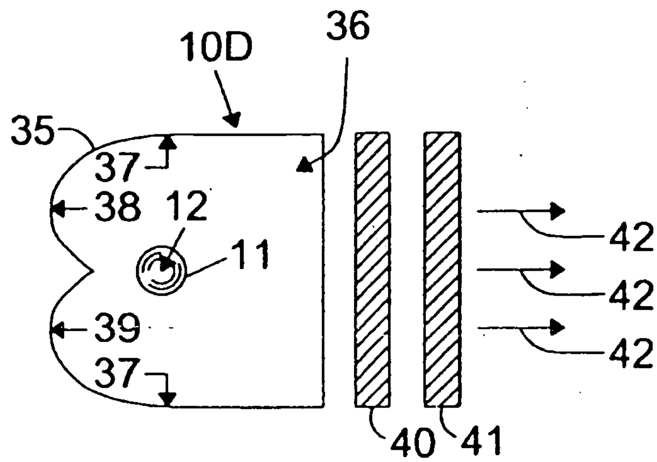


FIG. 7

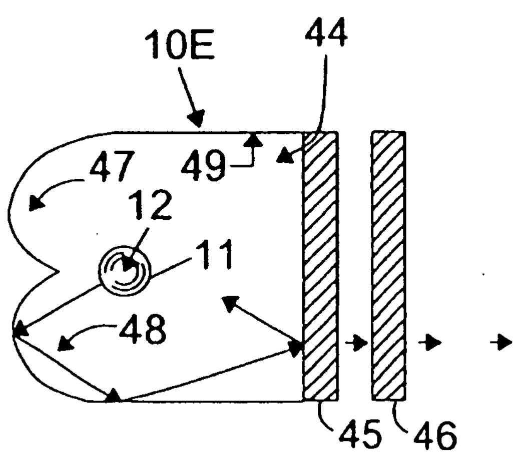


FIG. 4

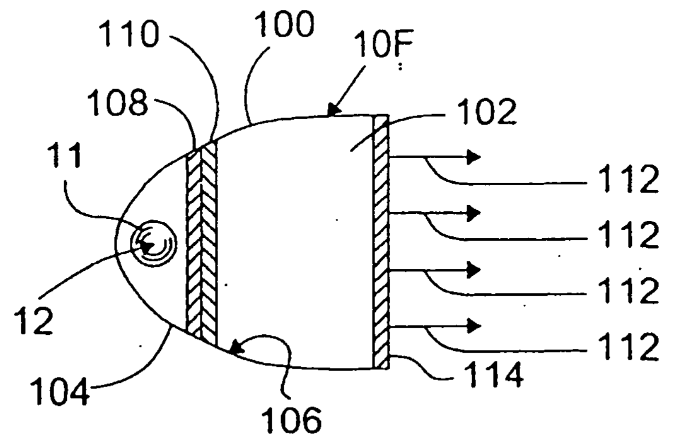


FIG. 5

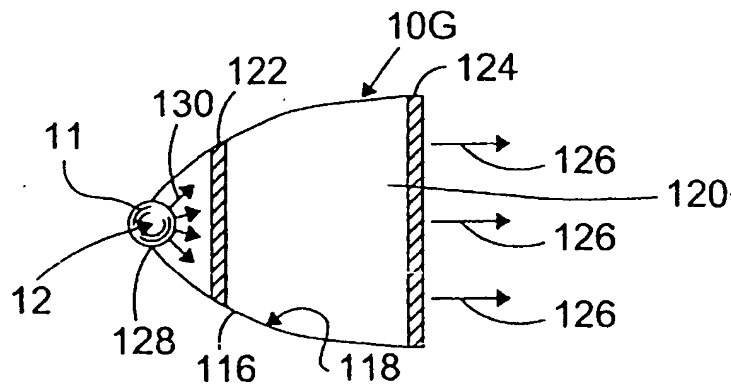
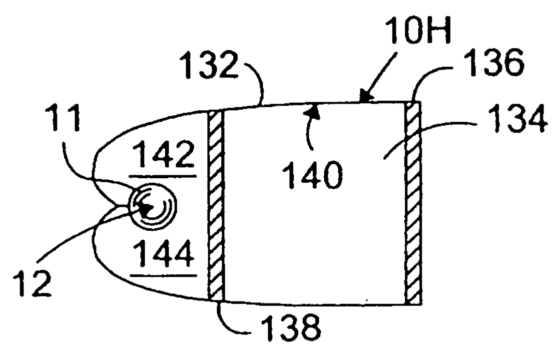


FIG. 8



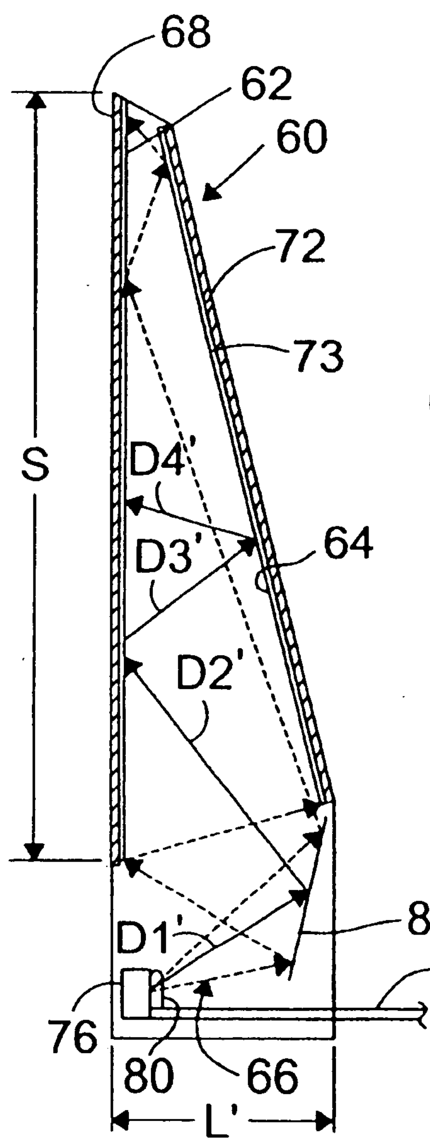

68
62
60
72
73
S
D4'
D3'
64
D2'
82
D1'
78
76
80
66
TO ANTENNA, CABLE
OR COMPUTER
L'

FIG. 9

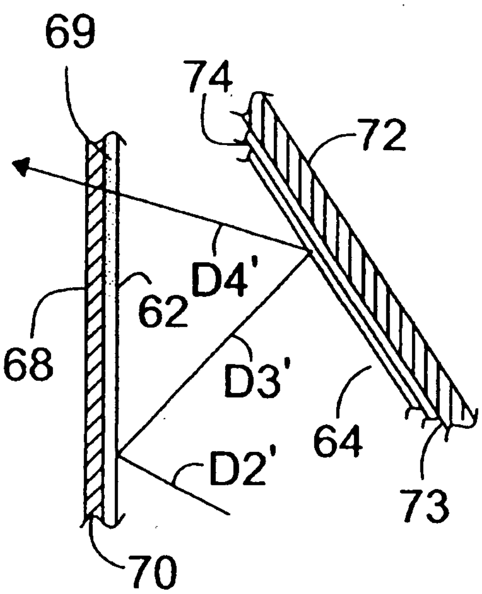

69
74
72
D4'
62
68
D3'
64
D2'
73
70

FIG. 10

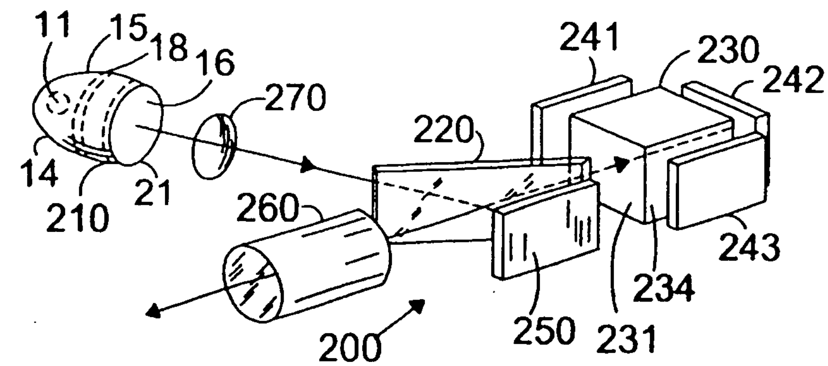

11
15
18
16
270
14
21
210
220
241
230
242
260
250
234
231
243
200

FIG. 11

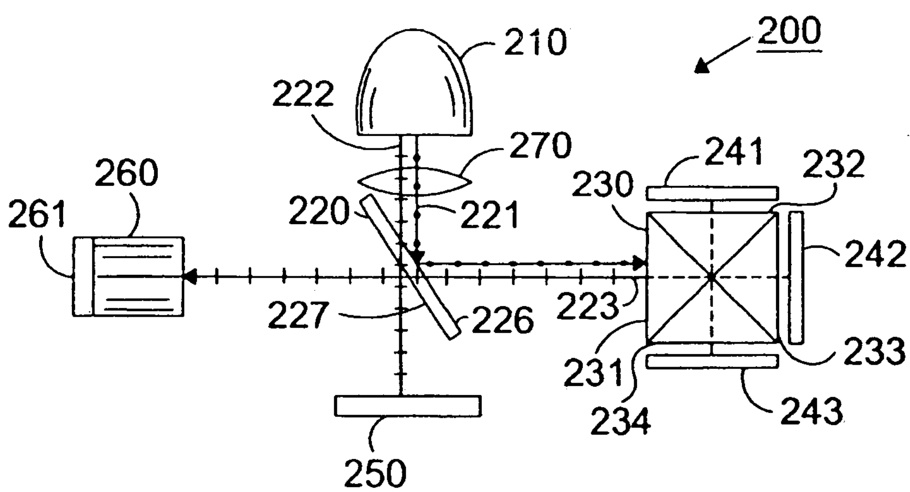
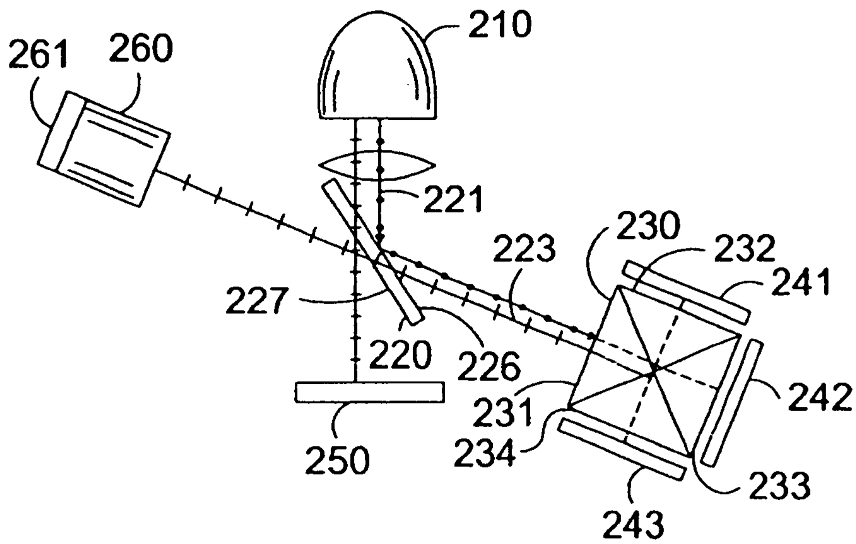

210
200
222
270
221
260
261
220
241
232
230
242
227
226
223
233
231
234
243
250

FIG. 12



210
261
260
221
230
232
223
241
227
220
226
242
231
234
233
250
243

FIG. 12A

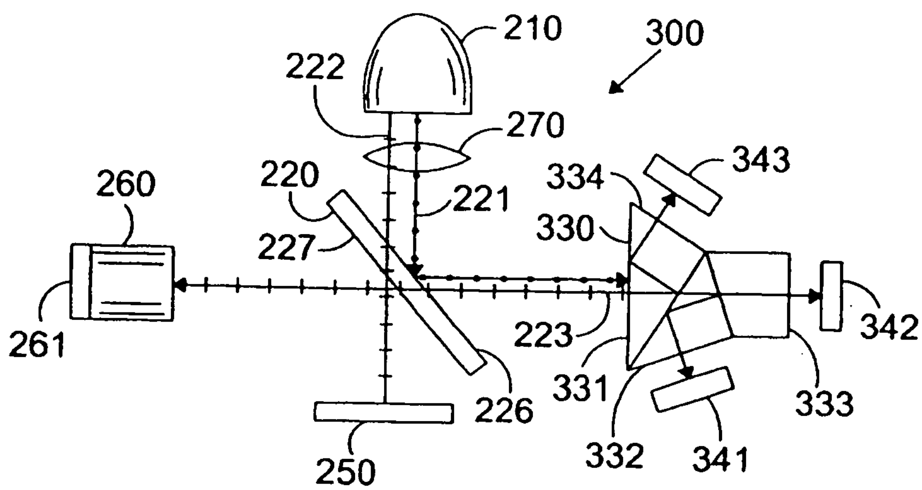

210
300
222
270
343
334
260
220
221
330
227
342
261
223
331
226
333
332
341
250

FIG. 13

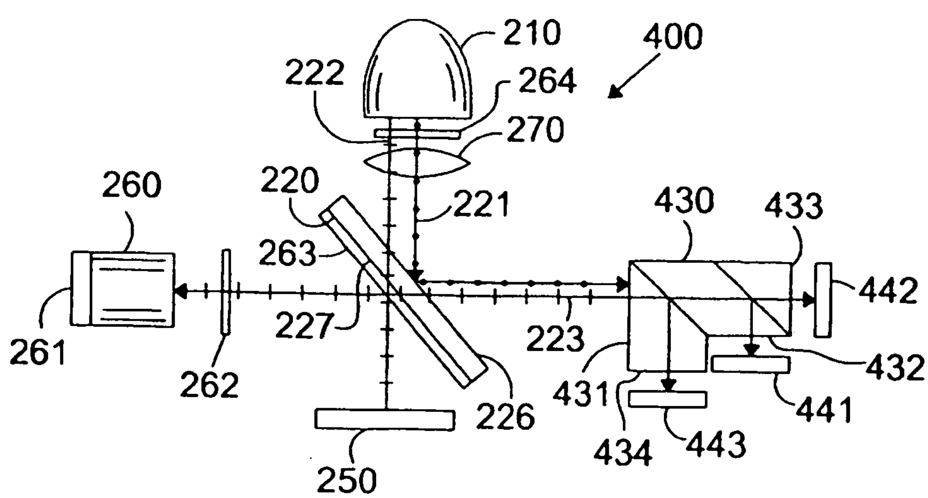

210
400
222
264
270
260
220
221
430
433
263
442
261
227
223
432
262
431
226
441
434
443
250

FIG. 14

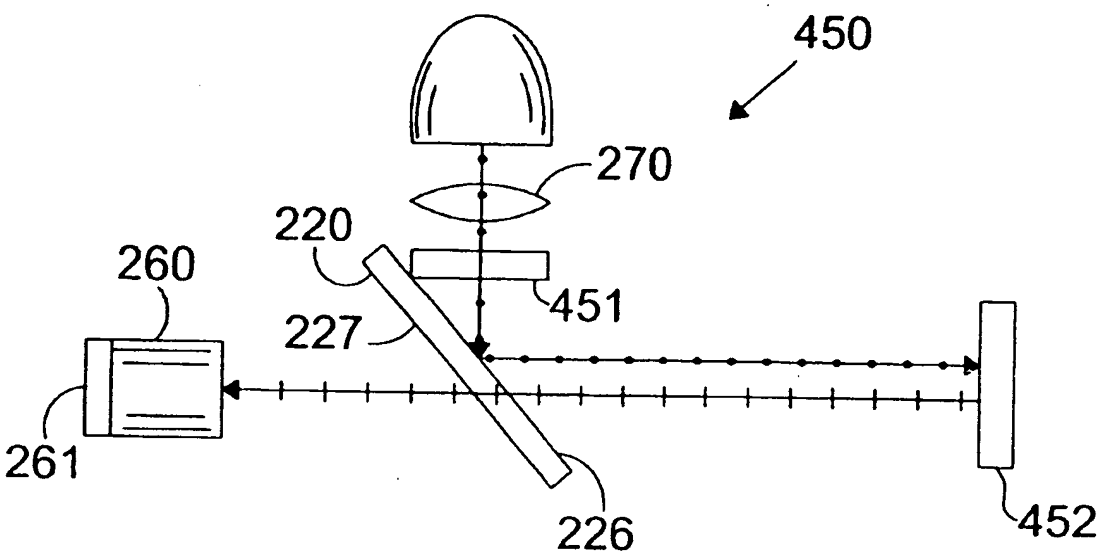


FIG. 14A

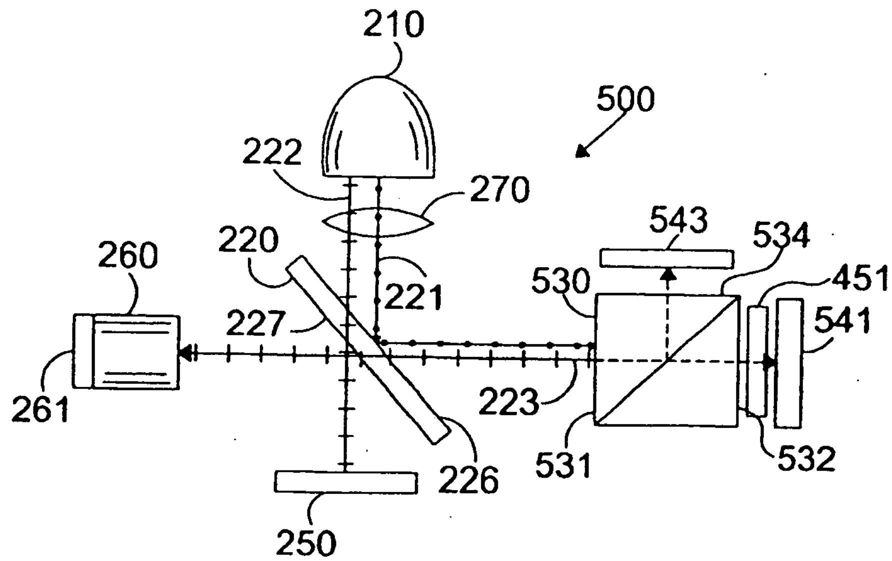

210
500
222
270
543
534
220
260
530
451
221
541
227
261
223
531
532
226
250

FIG. 15

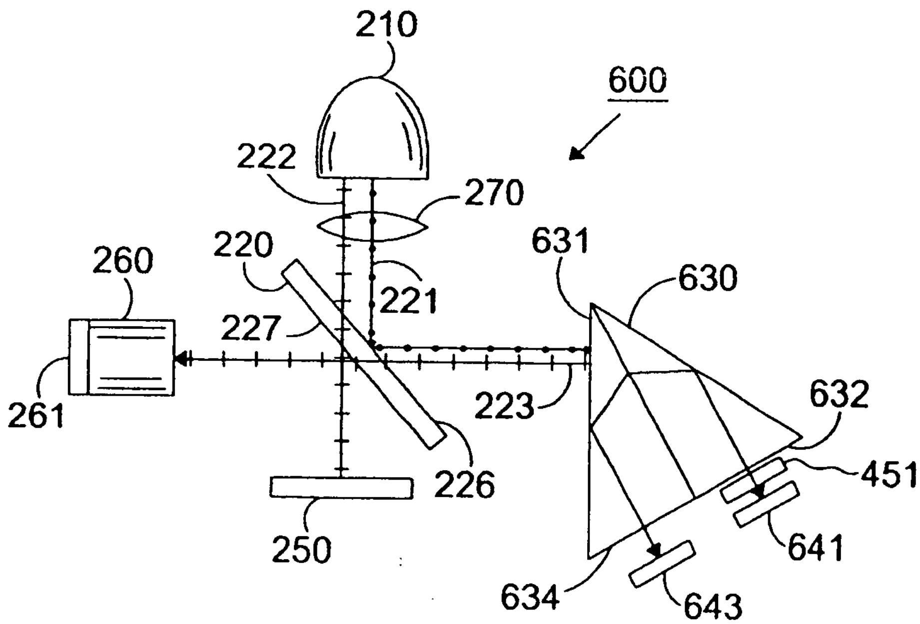
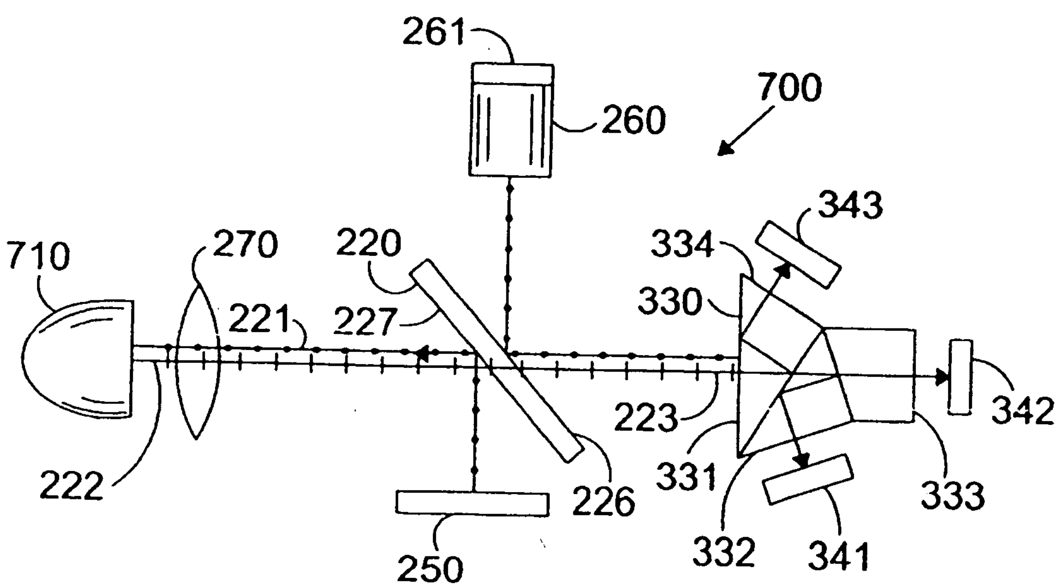

210
600
222
270
631
630
220
260
221
227
223
632
261
451
226
641
250
634
643

FIG. 16



261
260
700
710
270
220
221
227
343
334
330
342
223
222
226
331
333
250
332
341

FIG. 17

IMAGE PROJECTION SYSTEM ENGINE ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to image projection engines. More particularly, the present invention relates to an image projection engine that provides a polarized image for use in, for instance, a "folded" projection system.

2. Description of the Related Art

High power lamps are used for illumination applications beyond typical incandescent and fluorescent lamps. One type of lamp known as a high intensity discharge (HID) lamp consists of a glass envelope which contains electrodes and a fill which vaporizes and becomes a plasma when the lamp is operated.

Recently, a patent issued for a high power lamp that utilizes a lamp fill containing sulfur or selenium or compounds of these substances. U.S. Pat. No. 5,404,076, issued to Dolan et al. and entitled "Lamp Including Sulfur" discloses an electrodeless lamp utilizing a fill at a pressure at least as high as one atmosphere. The fill is excited at a power density in excess of 50 watts per square centimeter. A lamp utilizing the fill is excited at a power density of at least 60 watts per square centimeter. The Dolan et al. patent is incorporated herein by reference. Other pressures and power densities can be employed.

Projecting systems are used to display images on large surfaces, such as movie or television screens and computer displays. For example, in a front projection system, an image beam is projected from an image source onto the front side of a reflection-type angle transforming screen, which then reflects the light toward a viewer positioned in front of the screen. In a rear projection system, the image beam is projected onto the rear side of a transmission-type angle transforming screen and transmitted toward a viewer located in front of the screen.

Projection engine designs are not new. For example, in U.S. Pat. No. 5,453,859 (hereby incorporated by reference), a system is shown that uses a polarization beam splitter along with a dichroic "X-cube" to create a color image. Referring to FIG. 14 of that patent, it is seen that polarized light from a light source 91 is reflected by a polarization beam splitter to a dichroic prism 95. The reflected light is S-polarized, or polarized normal to the plane of incidence within the prism 93. This S-polarized light is then passed through a quarter wave plate 94, which circularly polarizes that S-polarized light. For each pixel that is in the "off" position, that circularly polarized light is reflected unchanged by the corresponding pixel of a reflective LCD 96, 97, and 98. Then, that circularly polarized light is restored to its original S-polarized state on the return path through the quarter wave plate 94. That light is then reflected back towards the light source by the prism 93.

For pixels that are to be lit, the LCDs 96, 97, and 98 convert some of the circularly polarized light to elliptically polarized light. When this light is passed through the quarter wave plate 94, the light passed will not be solely S-polarized, but will instead include a P-polarized component, which is passed through the prism 93, through a projection lens 99, and into whatever projection system is used.

Displaytech, Inc., in a 6-page technical disclosure entitled "FLC/VLSI Display Technology" and dated Dec. 1, 1995; Parfenov et al., in "Advanced optical schemes with liquid crystal image converters for display applications," SPIE Proceedings, Volume 2650, pages 173–179 (Jan. 29–31, 1996); and Baur et al., in "High performance liquid crystal device suitable for projection display," SPIE Proceedings, Volume 2650, pages 226–228 (Jan. 29–31, 1996), disclose background information on the use of liquid crystal devices to process video images. These papers are hereby incorporated by reference.

SUMMARY OF THE INVENTION

The present invention provides an improved projection engine. Polarized light from a light source is reflected by a polarizer/analyzer (such as a 3M DBEF material) which reflects only the S-polarized components of light and transmits P-polarized components of light.

One of the polarized components of light is passed to an image engine that forms an image by shifting the polarity of portions of the light. For example, the S-polarized light can be passed to a dichroic X-cube beam splitter/combiner (or other beam splitter/combiner for splitting the S-polarized light into red, green, and blue components when light passes through the beam splitter/combiner in a first direction and for combining red, green, and blue components when light passes through the beam splitter/combiner in a second direction) which provides red, green, and blue light to spatial light modulator type liquid crystal displays. Alternatively, the beam splitter/combiner could be omitted and a color sequential technique could instead be used to provide colored light. In addition, a combination of the two techniques can be employed. The liquid crystal displays alter the polarity of the S-polarized light so that the reflected light is S-polarized, P-polarized, or elliptically polarized with both S-polarized and P-polarized components, depending on the amount of light that is to be transmitted to the display and the type of spatial light modulator. This light, if the polarity is unchanged, is reflected back to the light source by the polarizer/analyzer. Any P-polarized components, however, are passed through the polarizer/analyzer and on to the display.

Using this system, a variable intensity of each color can be applied with each pixel, and each resulting pixel is generated through the coaligned colors of light. Further, the optics are highly efficient, because virtually all of the source light of an "on" pixel is transmitted for display and virtually all of the source light of an "off" pixel is returned to the lamp where its energy may be recovered.

The beam splitter/combiner is chosen such that there is either no alteration of the polarity of light passing therethrough (the preferred situation) or a consistent, predictable alteration of the polarity so that compensation for the alteration of polarity can be made by controlling the LCDs. For example, if a beam splitter/combiner that is chosen for use alters the polarity of green light passing back and forth through it one quarter wave total, the LCDs for the green light would be adjusted such that if one wanted a dark pixel, one would cause the LCD to alter the polarity back one quarter wave in the opposite direction to end up with a green light beam that is reflected back at the source from the DBEF reflective surface.

The present invention preferably comprises a projection display apparatus comprising:

- a source of rays of polarized light;
- a 3M DBEF reflecting polarizer aligned at an angle to the rays of polarized light for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

a beam splitter/combiner, having a first, primary incidence plane aligned with the reflected polarized light for splitting the rays of polarized light which are polarized in the second direction into blue, green, and red light rays;

a first reflecting polarizing LCD for receiving the blue light rays from the beam splitter/combiner, shifting the polarization of none, some, or all of the blue light rays, and directing the blue light rays back into the beam splitter/combiner;

a second reflecting polarizing LCD for receiving the green light rays from the beam splitter/combiner, shifting the polarization of none, some, or all of the green light rays, and directing the green light rays back into the beam splitter/combiner;

a third reflecting polarizing LCD for receiving the red light rays from the beam splitter/combiner, shiffing the polarization of none, some, or all of the red light rays, and directing the red light rays back into the beam splitter/combiner; and

a lens for receiving and transmitting substantially all of the rays of polarized light which are polarized in the first direction and which have passed from the beam splitter/combiner through the DBEF reflecting polarizer.

Preferably, the source of rays of polarized light comprises a "light-pumped" source that can re-absorb and re-emit unused reflected light; when a "light-pumped" source is used, the apparatus can also include a mirror aligned at substantially a 90° angle to the rays of polarized light as the rays exit the source for reflecting back to the source the rays of polarized light which are polarized in a first direction and which pass through the DBEF reflecting polarizer without first passing through the beam splitter/combiner. The source of rays of polarized light preferably includes a reflecting polarizing filter for passing substantially all of the rays of polarized light which are polarized in the second direction and for reflecting substantially all of the other rays of light. The source of rays of polarized light preferably also comprises a reflecting filter for passing substantially all rays of blue light, green light, and red light, and for reflecting substantially all rays of light which are not blue light, green light, or red light.

A condenser lens can advantageously be interposed along the path of the rays of polarized light between the source of rays of polarized light and the DBEF polarizing reflector.

The source of rays of polarized light can advantageously comprise:

an electrodeless lamp body that defines a chamber;

a gas contained within the chamber;

electrodes positioned externally of the lamp chamber for producing radio frequency energy that excites the gas, forming a plasma light source of intense heat that emits a light beam, wherein the electrodes are not subjected to the intense heat generated at the plasma; and

a reflector positioned next to the lamp body for redirecting some of the light emitted by the light source back to the lamp using the reflector so that the lamp reabsorbs light energy to intensify the light source, wherein the reflector includes a polarizing filter that is positioned to receive and polarize the light beam.

The projection display apparatus of the present invention can advantageously be used as an image source in a projection apparatus for producing an image display on a display surface comprising a display surface, an optical device which is reflective of some light and transmissive of other light; and means for transmitting light from the image source to the display surface such that the light travels an image path which reaches the optical device twice on its way to the display surface.

The present invention also comprises a method of producing a visual image comprising:

providing a source of rays of polarized light;

directing the rays of polarized light onto a 3M DBEF reflecting polarizer aligned at an angle to the rays of polarized light for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

reflecting the light rays which are aligned in the second direction from the 3M DBEF reflecting polarizer into a beam splitter/combiner having a first, primary incidence plane aligned at an angle to the 3M DBEF reflecting polarizer for splitting the rays of polarized light which are polarized in the second direction into blue, green, and red light rays;

valving the blue light rays in a first reflecting polarizing LCD for receiving the blue light rays from the beam splitter/combiner, by shifting the polarization of none, some, or all of the blue light rays 90°, and directing the blue light rays back into the beam splitter/combiner;

valving the green light rays in a second reflecting polarizing LCD for receiving the green light rays from the beam splitter/combiner, by shifting the polarization of none, some, or all of the green light rays 90°, and directing the green light rays back into the beam splitter/combiner;

valving the red light rays in a third reflecting polarizing LCD for receiving the red light rays from the beam splitter/combiner, by shifting the polarization of none, some, or all of the red light rays 90°, and directing the red light rays back into the beam splitter/combiner;

electrically controlling the LCDs;

reflecting the blue, green, and red light rays polarized in the second direction from the 3M DBEF reflecting polarizer back to the source of rays of polarized light; and

transmitting the blue, green, and red light rays polarized in the first direction through the 3M DBEF reflecting polarizer to a lens which transmits the blue, green, and red light rays polarized in the first direction to produce a visual image. In this method, the source of rays of polarized light preferably comprises a "light-pumped" source that can re-absorb and re-emit unused reflected light. The method preferably further comprises the step of reflecting back to the source of rays of polarized light the rays of polarized light which are polarized in a first direction and which pass through the DBEF reflecting polarizer without first passing through the beam splitter/combiner from a mirror aligned at substantially a 90° angle to the rays of polarized light as the rays exit the source.

The source of rays of polarized light preferably includes a source of light and a reflecting polarizing filter for passing substantially all of the rays of polarized light which are polarized in the second direction and for reflecting substantially all of the other rays of light.

The source of rays of polarized light can also include reflecting filter for passing substantially all rays of blue light, green light, and red light, and for reflecting substantially all rays of light which are not blue light, green light, or red light.

In the method of the present invention, the LCDs are preferably analog LCDs.

The apparatus of the present invention can be broadly described as a projection display apparatus comprising:

an optically pumpable source of rays of polarized light that can re-emit unused light returned to it;

a wide angle reflecting polarizer for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

at least one reflecting polarizing LCD for receiving the light rays from the reflecting polarizer, shifting the polarization of none, some, or all of the light rays, and directing the light rays back towards the wide angle reflecting polarizer;

a lens for receiving and transmitting substantially all of the rays of polarized light whose polarization has been shifted by the at least one reflecting polarizing LCD; and

means for returning the rays of polarized light whose polarization has not been shifted by the at least one reflecting polarizing LCD to the source of rays of polarized light to optically pump the source.

The method of the present invention can broadly be described as a method of producing a visual image comprising:

providing an optically pumpable source of rays of polarized light that can re-emit unused light returned to it;

directing the rays of polarized light onto a wide angle reflecting polarizer for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

using at least one reflecting polarizing LCD, shifting the polarization of none, some, or all of the light rays, and directing the light rays back towards the wide angle reflecting polarizer;

receiving with a lens and transmitting through the lens substantially all of the rays of polarized light whose polarization has been shifted by the at least one reflecting polarizing LCD; and

returning the rays of polarized light whose polarization has not been shifted by the at least one reflecting polarizing LCD to the source of rays of polarized light to optically pump the source.

BRIEF DESCRIPTION OF THE DRAWINGS

For a further understanding of the nature and objects of the present invention, reference should be had to the following detailed description, taken in conjunction with the accompanying drawings, in which like parts are given like reference numerals, and wherein:

FIG. 1 is a sectional view of the preferred embodiment of the apparatus of the present invention;

FIG. 1A is a fragmentary view of the preferred embodiment of FIG. 1;

FIG. 2 is a sectional elevational view of a second embodiment of the apparatus of the present invention;

FIG. 3 is a sectional elevational view of a third embodiment of the apparatus of the present invention;

FIG. 4 is a sectional elevational view of a fourth embodiment of the apparatus of the present invention;

FIG. 5 is a sectional elevational view of a fifth embodiment of the apparatus of the present invention;

FIG. 6 is a sectional view of the sixth embodiment of the apparatus of the present invention;

FIG. 7 is a sectional view of the seventh embodiment of the apparatus of the present invention;

FIG. 8 is a sectional view of the eighth embodiment of the apparatus of the present invention;

FIGS. 9 and 10 are side views of the preferred embodiment of the apparatus of the present invention showing a rear projection video system;

FIG. 11 is a perspective view of the projection display apparatus of an embodiment of the present invention;

FIG. 12 is a top view of the projection display apparatus of an embodiment of the present invention;

FIG. 12A is a top view of the projection display apparatus of an alternative embodiment of the present invention;

FIG. 13 is a top view of the projection display apparatus of an embodiment of the present invention;

FIG. 14 is a top view of the projection display apparatus of an alternative embodiment of the present invention;

FIG. 14A is a top view of an embodiment of the present invention that uses sequential color;

FIG. 15 is a top view of the projection display apparatus of another embodiment of the present invention;

FIG. 16 is a top view of the projection display apparatus of another alternative embodiment of the present invention; and

FIG. 17 is a top view of the projection display apparatus of yet another alternative embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

U.S. application Ser. No. 08/581,108, filed Dec. 29, 1995, and entitled "Projecting Images," is hereby incorporated by reference.

Turning to the drawings, FIG. 1 shows generally an embodiment of the lamp apparatus of the present invention, designated generally by the numeral **10A**, for use with the projector lamp optics assembly of the preferred embodiment of the present invention. A high efficiency lamp apparatus **10A** includes a bulb **11** having a hollow interior **12** that contains a gas such as sulfur gas or selenium gas or some other lamp optimally capable of being optically pumped. The gas in bulb **11** can be excited to a plasma state so as to produce a high intensity light source. The gas fill is excited by electrodes E (see FIG. 1A), which provide radio frequency (or other appropriate frequency) energy to excite the fill; electrodes E are not subjected to the intense heat of the plasma inside bulb **11**. Lamp apparatus **10A** could also include a non-mercury containing metal halide lamp which works with fusion and is electrodeless. The fill may be high or low pressure.

Generally, redirecting light to a lamp will cause that lamp to fail. This is not true, however, with certain types of electrodeless lamps that can reabsorb such light. Such lamps include those shown in the Dolan patent, previously incorporated by reference, as well as certain lamps containing selenium gasses or non-mercury metal halide gasses. The advantage of using such lamps in the disclosed systems is that generally only certain colors or polarities of light are useable and needed in these systems. Therefore, with appropriate filtering (illustrated by FIGS. 1–8), only desired polarities or colors of light are passed, and the remainder is reflected back to the plasma formed in the electrodeless

lamps for re-absorption and re-emission. This improves the efficiency of the light source.

A shaped (for instance, parabolic) annular reflector housing 14 is positioned about and spaced from bulb 11 as shown in FIG. 1. The housing 14 is hollow, defined by a wall 15 and an open end portion 16. The wall 15 has a reflecting surface 17. Housing 14 can be made of, for example, ceramic material.

A first transversely positioned screen 18 is interposed across the path of a light beam 19 that is travelling from the bulb 11 through the open end portion 16 in the direction of arrows 20. A second screen 21 is interposed across the path 19 and on the opposite side of screen 18 from bulb 11 as shown in FIG. 1.

The first screen 18 is preferably an interference filter (for example a dichroic filter or dichroic mirror), that reflects certain colors of light while allowing others to pass through. The screen 18 is preferably selected to pass red, green and blue light, reflecting undesired colors back to the bulb 11 and the reflector surface 17. By reflecting light other than desired colors back to the bulb 11, the lamp 10 becomes more efficient because it allows conversion of redirected light back to useful wavelengths. In FIG. 1, the lamp 10A has the screen 18 mounted inside the reflector housing 14 and the screen 21 mounted at opening 16. The screen 18 and the screen 21 each extends at its periphery to the wall 15.

The screen 21 is a reflecting polarizer that only allows a certain polarity of light to pass through as indicated by the arrows 20. The reflecting polarizer 21 reflects light of the wrong polarity back to the bulb 11. Therefore, in the lamp 10A, emitted light indicated as 20 has been filtered to be of a desired portion(s) of the color spectrum and of a desired polarity.

In FIGS. 2–8, other embodiments of the lamp 10 are shown. FIG. 2 illustrates a lamp 10B similar to that of FIG. 1, with a pair of screens 26 and 27 positioned externally or covering an opening 23 of a reflector housing 22 including reflecting surface 24. The screen 26 is preferably an interference filter, and the screen 27 is preferably a reflecting polarizer. FIG. 3 illustrates an alternative lamp 10C, in which three optical elements 31, 32, and 33 are positioned external to a housing 28 and either away from or covering an open end portion 29 of the housing 28. The element 31 is preferably a reflecting polarizer, the element 32 is preferably an interference filter, and the element 33 is a clean-up absorbing filter. FIG. 4 illustrates another alternative lamp 10F, with an element 108 that is an interference filter and an element 110 that is a reflecting polarizer both mounted within a reflector housing 100, while an additional polarizing filter 114 covers an open end 102 of the reflector housing 100. FIG. 5 illustrates an alternative lamp 10G where a reflective housing 116 assumes a parabolic shape. FIG. 6 illustrates lamp 10D in which a reflector housing 35 has an inner reflecting surface 37 with double parabolic shapes and cross-sections. FIG. 7 illustrates an alternative lamp 10E, in which an opening 44 has an element 45 that is an interference filter, dichroic filter, or dichroic mirror, and an element 46, which is preferably a reflecting polarizer. FIG. 8 illustrates an alternative lamp 10H with dual parabolic reflectors that includes an internal element 138 that is preferably an interference filter and an element 136 covering an opening 134, where the element 136 is preferably a reflecting polarizer. All of these lamps 10 are intended to provide desired frequencies and polarities of light, while reflecting undesired light for re-absorption and re-emission by the fill within the bulb 11.

FIGS. 9 and 10 show a rear projection video system 60 that includes a linear reflecting polarizer 62 and an achromatic retarder 64 that allow light in a projected image 66 to reflect from a display screen 68 at one instance and to pass through the screen 68 at another instance. This allows for "optical folding," which allows the video system 60 to be very shallow yet project a large image, as described in the previously incorporated U.S. patent application entitled "Projecting Images." For the video system 60 to work properly, the image source 76 must produce polarized light. A wide variety of other types of video systems employ polarization in image formation.

FIGS. 11 and 12 show the projection display apparatus or engine 200 of a first embodiment of the present invention. The projection display apparatus 200 comprises a source 210 of rays of polarized light, such as the light source 10A of FIG. 1, a polarizer/analyzer (reflecting polarizer) 220, an X-cube beam splitter/combiner 230, reflecting polarizing LCDs 241, 242, 243, a mirror 250, a projection lens 260, an optional clean-up polarizing filter 261, and an optional condenser lens 270. The projection display apparatus 200 (or any of the remaining embodiments, which employ a wide angle reflecting polarizer) can advantageously be used as the image source 76 in the video system 60 shown in FIGS. 9 and 10.

The reflecting polarizer 220 (preferably made of DBEF, or double brightness enhancement film, commercially available from Minnesota Mining & Manufacturing Company, though some other wide angle reflecting polarizer could be used) is preferably aligned at approximately a 45° angle to the rays of polarized light for passing substantially all of the components of light polarized in a first direction (P-polarized in a direction parallel to the plane of incidence) and for reflecting substantially all of the components of light polarized in a second direction (S-polarized, in a direction normal to the plane of incidence). The reflecting polarizer 220 could be set to work at angles other than 45°, with corresponding changes to the remainder of the optics to account for the other angles. FIG. 12A shows an alternative embodiment in which the angle of incidence of the light projected by the source 210 to the reflecting polarizer 220 is other than 45°. When the reflecting polarizer is an appropriate wide angle reflecting polarizer, such as DBEF, angles other than 45° can be chosen.

The X-cube beam splitter/combiner 230 has a first, primary incidence plane 231 aligned at approximately a 45° angle to the reflecting polarizer 220. The purpose of the X-cube beam splitter/combiner 230 is to split the rays of S-polarized light into blue, green, and red light rays and to direct substantially all of a first light color (such as blue light rays) through a second plane of the X-cube beam splitter/combiner 230, to direct substantially all of a second light color (such as green light rays) through a third plane of the X-cube beam splitter/combiner 230, and to direct substantially all of a third light color (such as red light rays) through a fourth plane of the X-cube beam splitter/combiner 230. While red, green, and blue are shown in this embodiment, any three colors suitable as primary colors could be used.

A first reflecting polarizing LCD 241 receives the blue light rays from X-cube beam splitter/combiner 230. The reflecting polarizing LCD 241 (and the reflecting polarizing LCDs 242 and 243) is preferably a liquid crystal spatial light modulator. These LCDs operate as a type of variably birefringent switch. In a first position, the reflected light is essentially unaffected by the LCD, resulting in the reflective light being S-polarized as was the incident light. When the liquid crystals are fully energized, however, the liquid

crystal display effectively retards the incident light by a half wave, resulting in a rotation of the polarity by 90°. Thus, the S-polarized light is reflected as P-polarized light. In between, if appropriate for the particular LCD, components of each are apparent, resulting in elliptically polarized or circularly polarized light, with a greater and lesser degree of polarization in a particular direction according to the amount of voltage applied to that particular pixel of the LCD of the reflecting polarizing LCD 241. For alignment purposes, the optical axis of the liquid crystal display is aligned at a 45° angle relative to the angle of polarization of the incident S-polarized light.

Thus, the reflecting polarizing LCD 241 shifts the polarization of the blue light rays such that the reflected light has varying degrees of S-polarized components and P-polarized components, varying from entirely S-polarized to entirely P-polarized. These rays are directed back into the X-cube beam splitter/combiner 230.

The second reflecting polarizing LCD 242 is used for receiving the green light rays from X-cube beam splitter/combiner 230, and like the first reflecting polarizing LCD 241 shifts the polarization of the S-polarized light so that the result is no, some, or all P-polarized light. The green light rays are then directed back into the X-cube beam splitter/combiner 230. The third reflecting polarizing LCD 243 does the same for the red light rays from the X-cube beam splitter/combiner 230.

In operation, radio-frequency (such as microwave) energy is used to excite the fill in light bulb 11, and light is emitted therefrom. Some of this light (the blue, green, and red components) passes through reflecting filter 18. The rest of the light is reflected by reflecting filter 18 back into light bulb 11.

Of the light which passes from the bulb 11 through the filter 18, substantially all of the transmitted light is S-polarized, while the remaining light is reflected back towards the bulb 11 from the filter 21. A small amount of P-polarized light 222 may escape through filter 21, but it will pass unreflected through reflecting polarizer 220, reflect off of a mirror 250, and back through a second surface 227 of the reflecting polarizer 220 towards the filter 21, through which it will pass. The insulated filter 21 does not normally pass P-polarized light in a first direction when the light is coming from the bulb 11, but normally passes P-polarized light in a second direction when the light is coming from outside of the light source 210. This initially P-polarized light is then directed to the bulb 11 for optical pumping.

It will be appreciated that the mirror 250 is not strictly necessary. This is especially true if the source 210 initially provides light of only the desired polarity. In that case, very little light will actually pass through the reflecting polarizer 220 anyway, so the mirror 250 can be eliminated. Even if the light is not prefiltered in this way, the mirror 250 could be eliminated without detracting from the spirit of the invention.

The S-polarized light 221, after passing through the filter 18 (and a condenser lens 270, if present) reflects off of a first surface 226 of the reflector 220 and into the first, primary incidence plane 231 of the X-cube beam splitter/combiner 230. The X-cube beam splitter/combiner 230 then splits the rays of S-polarized light into blue, green, and red light rays and directs substantially all blue light rays through a second plane 232 of the X-cube beam splitter/combiner 230, directs substantially all green light rays through a third plane 233 of the X-cube beam splitter/combiner 230, and directs substantially all red light rays through a fourth plane 234 of the X-cube beam splitter/combiner 230.

The light is then reflected by the LCDs 241, 242, and 243, as described above. The LCDs 241, 242, 243 are electrically controlled, such as with television signals, signals from a personal computer, or other means discussed in co-pending U.S. patent application entitled "Projecting Images." As discussed above, the reflected light is either totally S-polarized (unchanged), totally P-polarized, or elliptically polarized with components of each.

Both the P-polarized and S-polarized components of the light rays 223 again pass through and out of the X-cube beam splitter/combiner 230. When the light strikes the reflecting polarizer 220, the P-polarity components pass through, while the S-polarity components are reflected. The P-polarized components pass through the projection lens 260 and clean-up polarizing filter 261 (if present) and out of the apparatus 200, providing an image source for, for example, the apparatus 60. The remaining S-polarized components are reflected by the reflecting polarizer 220 and directed back into the light source 210, serving to "optically pump" the bulb 11.

Thus, as one will appreciate from a description of FIGS. 11 and 12, substantially all light emanating from bulb 11 is either transmitted through projecting lens 260 or is reflected back into bulb 11 for re-use (perhaps after sufficient downshifting takes place).

The LCDs 241, 242, 243 currently can be analog LCDs in the sense that the amount of polarization change for a pixel is related to the voltage level applied to that pixel. This allows the intensity of each color to be individually adjusted, providing for multiple colors. Alternatively, the LCDs 241, 242, 243 can be ferroelectric LCDs, where each pixel is instead only on or off, and then one pulse width modulates within each frame and/or performs frame-to-frame modulation to approximate a desired brightness for a color.

FIG. 13 is a top view of the projection display apparatus 300 of an embodiment of the present invention. The projection display apparatus 300 is essentially the same as the apparatus 200, but X-cube beam splitter/combiner 230 of the apparatus 200 is replaced with a Phillips prism 330, and the reflecting polarizing LCDs 241, 242, 243 are replaced with the reflecting polarizing LCDs 341, 342, 343, respectively. The Phillips prism 330 includes a plane 334 through which red light is transmitted, a plane 333 through which green light is transmitted, and a plane 332 through which blue light is transmitted. The reflecting polarizing LCDs 341, 342, 343 work in the same manner as the reflecting polarizing LCDs 241, 242, 243.

FIG. 14 is a top view of the projection display apparatus 400 of an alternative embodiment of the present invention. The projection display apparatus 400 is essentially the same as the apparatus 200, but X-cube beam splitter/combiner 230 of the apparatus 200 is replaced with a prism 430, the reflecting polarizing LCDs 241, 242, 243 are replaced with the reflecting polarizing LCDs 441, 442, 443, respectively, and a number of optional polarizing filters are included in the apparatus 400.

The optional polarizing filters shown in FIG. 14 include the clean-up polarizing filter 261, a pre-polarizer 264 immediately downstream of the lamp 210 to provide clean-up polarization, an absorptive polarizer 263 laminated to the polarizer/analyzer 220, and/or an absorptive polarizer 262 between polarizer/analyzer 220 and lens 260 for clean-up. Any or all of the filters 261, 262, 263, and 264 could be omitted, or all could be included, in apparatus 400; likewise, any or all of these filters could be included in the apparatus of other embodiments of the present invention described herein.

The prism 430 includes a plane 434 through which red light is transmitted, a plane 433 through which green light is transmitted, and a plane 432 through which blue light is transmitted. The reflecting polarizing LCDs 441, 442, 443 work in the same manner as the reflecting polarizing LCDs 241, 242, 243.

FIG. 14A is a top view of the projection display apparatus 450 of another embodiment of the present invention. The projection display apparatus 450 is similar to the apparatus 200 but only a single reflecting/polarizing LCD 452 is used and no beam splitter/combiner is utilized. A color wheel or shutter 451 is provided prior to the polarizer/analyzer 220. The color wheel 451 acts to provide time-sequential red, green, and blue light, so that the projection display apparatus 450 is a color sequential system. The reflecting/polarizing LCD 452 then receives red, green and blue data during the appropriate period in synchronization with the color wheel 451. The viewer's eye then integrates the three separate images into a single multicolor image.

FIG. 15 is a top view of the projection display apparatus 500 of another embodiment of the present invention. The projection display apparatus 500 is similar to the apparatus 200, but X-cube beam splitter/combiner 230 of the apparatus 200 is replaced with a prism 530, and the reflecting polarizing LCDs 241 and 243 are replaced with the reflecting polarizing LCDs 541 and 543, respectively. The reflecting polarizing LCD 242 is omitted.

The prism 530 includes a plane 534 through which a single color light, for example, red, is transmitted and a plane 532 through which two colors of light, blue and green for example, are transmitted. The reflecting polarizing LCDs 541 and 543 work in the same manner as the reflecting polarizing LCDs 241 and 243. Reflecting polarizing LCD 541 operates like reflective polarized LCD 452 of FIG. 14A, except that sequential modulation is done of only two colors.

FIG. 16 is a top view of the projection display apparatus 600 of another alternative embodiment of the present invention. The projection display apparatus 600 is similar to the apparatus 500, but the prism 530 of the apparatus 500 is replaced with a prism 630, and the reflecting polarizing LCDs 541 and 543 are replaced with the reflecting polarizing LCDs 641 and 643, respectively.

The prism 630 includes a planar surface 634 through which a first color of light is transmitted and a planar surface 632 through which two other colors of light are transmitted. The reflecting polarizing LCDs 641 and 643 work in the same manner as the reflecting polarizing LCDs 541 and 543.

FIG. 17 is a top view of the projection display apparatus of yet another alternative embodiment of the present invention, projection display apparatus 700. The projection display apparatus 700 is perhaps most similar to the projection display apparatus 300, but works on a reflective, rather than transmissive, principle. In apparatus 700, the light source 210 is replaced with a light source 710, and the light source 710 primarily produces P-polarized light 222 and only incidentally produces S-polarized light 221. In the apparatus 700, the positions of the light source 710 and the lens 260 are switched; mirror 250 still reflects light of an undesired polarity back into the light source 710, but in this case the undesired polarity is S-polarized light. The reflecting polarizing LCDs 341, 342, 343 work in the same manner as in the apparatus 300, changing the polarity of so much of the light as is desired to be transmitted to lens 260.

Apparatus 200, 400, 450, 500, and 600 could all be modified to reflect from polarizer/analyzer 220 rather than transmit through polarizer/analyzer 220 an image into lens 260.

For monochrome applications, one could modify the projection display apparatus 200 to omit the beam splitter/combiner 230 and LCDs 241 and 243. Alternatively, if one wished to use a reflective principle with a monochrome application, one could use the apparatus 700 but omit the prism 330 and the LCDs 341 and 343.

The projection display apparatus 200, 300, 400, 450, 500, 600, and 700 is advantageous over systems such as those shown in U.S. Pat. No. 5,453,859 in part because a wide angle reflecting polarizer (such as 3M DBEF) is used as the reflecting polarizer 220. Further, the filters 21 and 18 and the mirror 250, if used, cause a substantial portion of the light to be redirected into lamp 11 for absorption and re-emission. Additionally, any light reflected from an "off" pixel in the reflecting, polarizing LCDs is reflected back to the lamp 11 by the action of the LCD and the polarizer/analyzer 220 as the "off" pixel light has not been retarded by the LCD, so the polarization is such that the light is reflected by the polarizer/analyzer 220 back to the lamp 11. Thus, efficiency is increased at a system level due to these types of reflected light.

As used herein, "wide angle reflecting polarizer" means a reflecting polarizer that substantially transmits light of one polarization and reflects light of another through a wide variation in angles. Typical reflecting polarizers only operate properly at an angle very close to the Brewster angle. Wide angle refection polarizers operate at a variety of angles.

It will also be appreciated that a variety of other optical components can be included in the embodiments disclosed in FIGS. 11–17. For example, the light out of the source 210 could be immediately polarized, with the needed polarity of light reflected into the source. This could occur, for example, between the lens 270 and the source 210. Further, the lens 270 could be placed at different points in the optical path without detracting from the spirit of the invention. Also, although a variety of devices are shown for creating the polarized image, the specific device is not critical. A wide variety of image engines which create a polarized image could be used with the wide angle reflecting polarizer in a system according to the invention. For example, instead of providing three LCDs 241, 242, and 243 as shown in FIG. 12, a color sequential system using a single LCD could be used. By using a wide angle reflecting polarizer in a system that utilizes polarization to create images, the tolerances are relaxed and the system becomes easier to construct and maintain.

The foregoing embodiments are presented by way of example only; the scope of the present invention is to be limited only by the following claims.

What is claimed is:

1. A projection display apparatus comprising:

a light source adapted to provide a light beam;

a wide angle reflecting polarizer adapted to pass substantially all light of a first polarization component of the light beam, and to reflect substantially all light of a second polarization component of the light beam; and

an image engine adapted to receive one of the first or second polarization components and to return to said wide angle reflecting polarizer a polarized image in which polarization of the one of the first or second polarization components is shifted corresponding to an image to display to include portions of the second or first polarization components, wherein the image engine further includes a prism for splitting rays of polarized light received from the reflecting polarizer into the first and second color band, wherein the first

color band is passed through a color wheel/shutter to a single LCD for color sequential operation, and wherein the second color band is passed to a second LCD.

2. The apparatus of claim 1, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

3. The apparatus of claim 1, further comprising a mirror positioned on an opposite side of the wide angle reflecting polarizer with respect to the light source.

4. The apparatus of claim 1, further comprising a means of modifying the direction of the rays of light.

5. The apparatus of claim 1, further comprising:

a projection apparatus for producing an image display on a display surface, the projection apparatus including:

a display surface;

an optical device; and

means for transmitting light from the image engine to the display surface such that the light travels an image path which reaches the optical device twice on its way to the display surface, for reflecting light from a display screen at one instance, and for passing through the display screen at another instance, wherein the optical device is reflective of some light and transmissive of other light, and the display surface is substantially coextensive with the optical device.

6. The apparatus of claim 1, wherein the image engine receives the first polarized portion passed through said wide angle reflecting polarizer.

7. The apparatus of claim 1, wherein the image engine receives the second polarized portion reflected from said wide angle reflecting polarizer.

8. The apparatus of claim 1, wherein the beam of light is directed by the light source to the wide angle reflecting polarizer at an angle substantially 45° from a surface formed by the reflecting polarizer.

9. The apparatus of claim 1, wherein the beam of light is directed by the light source to the wide angle reflecting polarizer at an angle other than substantially 45° from a surface formed by the reflecting polarizer.

10. A projection display apparatus comprising:

a source of rays of polarized light;

a wide angle reflecting polarizer aligned at an angle to the rays of polarized light for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

a prism for splitting incident rays of polarized light from the reflecting polarizer into a first and second color bands of rays;

a color wheel/shutter for receiving the first color band of rays from the prism and for sequentially passing rays of a first color and of a second color in the first color band;

a first reflecting polarizing LCD for receiving the sequentially passed rays of the first color and of the second color in the first color band, for shifting the polarization of none, some, or all of the sequentially passed rays, and for directing the rays back into the prism;

a second reflecting polarizing LCD for receiving the second color band for rays from the beam splitter/combiner, for shifting the polarization of none, some, or all of the second color band of rays, and for directing the rays back into the prism; and

a lens for receiving and transmitting substantially all of the rays of polarized light whose polarity has been shifted and which have passed from the prism to the wide angle reflecting polarizer.

11. The apparatus of claim 10, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

12. The apparatus of claim 10, wherein the first color band is green and blue and wherein the second color band is red.

13. A projection display apparatus comprising:

a source of rays of polarized light;

a wide angle reflecting polarizer aligned at an angle to the rays of polarized light for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

a prism for splitting incident rays of polarized light from the reflecting polarizer into a first and second color bands of rays;

a color wheel/shutter for receiving the first color band of rays from the prism and for sequentially passing rays of a first color and of a second color in the first color band;

a first reflecting polarizing LCD for receiving the sequentially passed rays of the first color and of the second color in the first color band, for shifting the polarization of none, some, or all of the sequentially passed rays, and for directing the rays back into the prism;

a second reflecting polarizing LCD for receiving the second color band for rays from the prism, for shifting the polarization of none, some, or all of the second color band of rays, and for directing the rays back into the prism;

a lens for receiving and transmitting substantially all of the rays of polarized light whose polarity has been shifted and which have passed from the prism to the wide angle reflecting polarizer; and

a display surface for receiving rays from the lens.

14. The apparatus of claim 13, further comprising:

an optical device interposed between the lens and the display surface such that the rays travel an image path which reaches the optics twice before reaching the display surface, wherein the optical device is reflective of some light and transmissive of other light.

15. The apparatus of claim 13, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

16. The apparatus of claim 13, wherein the first color band is green and blue and wherein the second color band is red.

17. A projection display engine apparatus that receives a beam of light from a light source, comprising:

a wide angle reflecting polarizer for passing substantially all of a first polarized portion of the beam that is polarized in a first direction, and reflecting substantially all of a second polarized portion of the beam that is polarized in a second direction; and

an image engine that receives one of the first or second polarized portions and returns to said wide angle reflecting polarizer a polarized image in which the polarization of the one of the first or second polarized portions is shifted corresponding to an image to display to include components of the second or first polarized portions, wherein the image engine further includes a prism for splitting rays of polarized light received from the reflecting polarizer into a first and second color band, wherein the first color band is passed through a color wheel/shutter to a single LCD for color sequential

operation, and wherein the second color band is passed to a second LCD.

18. The apparatus of claim 17, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

19. The apparatus of claim 17 further comprising a mirror positioned on an opposite side of the wide angle reflecting polarizer with respect to the light source.

20. The apparatus of claim 17, further comprising a means of modifying the direction of the rays of light.

21. The apparatus of claim 17, further comprising:

a projection apparatus for producing an image display on a display surface, the projection apparatus including:

a display surface;

an optical device; and

means for transmitting light from the image engine to the display surface such that the light travels an image path wich reaches the optical device twice on its way to the display surface, for reflecting light from a display screen at one instance, and for passing through the display screen at another instance, wherein the optical device is reflective of some light and transmissive of other light, and the display surface is substantially coextensive with the optical device.

22. The apparatus of claim 17, wherein the image engine receives the first polarized portion passed through said wide angle reflecting polarizer.

23. The apparatus of claim 17, wherein the image engine receives the second polarized portion reflected from said wide angle reflecting polarizer.

24. The apparatus of claim 17, wherein the beam of light is directed from the light source to the wide angle reflecting polarizer at an angle substantially 45° from a surface formed by the reflecting polarizer.

25. The apparatus of claim 17, wherein the beam of light is directed from the light source to the wide angle reflecting polarizer at an angle other than substantially 45° from a surface formed by the reflecting polarizer.

26. A projection display apparatus comprising:

light source providing a beam of light;

a wide angle reflecting polarizer for passing substantially all of a first polarized portion of the beam that is polarized in a first direction, and reflecting substantially all of a second polarized portion of the beam that is polarized in a second direction;

an image engine that receives one of the first or second polarized portions and returns to said wide angle reflecting polarizer a polarized image in which the polarization of the one of the first or second polarized portions is shifted corresponding to an image to display to include components of the second or first polarized portion; and

a projection apparatus for producing an image display on a display surface, the projection apparatus comprising:

a display surface,

an optical device, wherein the optical device is reflective of some light and transmissive other light, and

means for transmitting light from the optical device to the display surface, wherein the means for transmitting light comprises an achromatic retarder, such that the light travels an image path that reaches the optical device twice and is retarded by the achromatic retarder on its way to the display surface.

27. A method of producing a visual image comprising:

providing a light source providing a beam of light;

directing the light onto a wide angle reflecting polarizer for passing substantially all of a first portion of the beam which is polarized in a first direction and for reflecting substantially all of a second portion of the beam which is polarized in a second direction;

receiving one of the first or second portions in an image engine:

shifting the polarity of the one of the first or second portions corresponding to an image to be displayed to include components of the second or first portion to yield a polarized image; and

returning the polarized image to the wide angle reflecting polarizer wherein the method is performed in a projection apparatus for producing an image display on a display surface, the projection apparatus comprising:

a display surface,

the wide angle reflecting polarizer, and

means for transmitting light from the wide angle reflecting polarizer to the display surface, wherein the means for transmitting light comprises an achromatic retarder, such that the light travels an image path that reaches the wide angle reflecting polarizer twice and is retarded by the achromatic retarder on its way to the display surface.

28. A projection system comprising:

a source of rays of polarized light;

a wide angle reflecting polarizer aligned at an angle to the rays of polarized light for passing substantially all of the rays of polarized light which are polarized in a first direction and for reflecting substantially all of the rays of polarized light which are polarized in a second direction;

a beam splitter/combiner, having a first, primary incidence plane aligned at an angle to the wide angle reflecting polarizer, for splitting incident rays of polarized light from the reflecting polarizer into a first second, and third color of light rays;

a first reflecting polarizing LCD for receiving the first color of light rays from the beam splitter/combiner, shifting the polarization of none, some, or all of the first color of light rays, and directing the first color of light rays back into the beam splitter/combiner;

a second reflecting polarizing LCD for receiving the second color of light rays from the beam splitter/combiner, shifting the polarization of none, some, or all of the second color of light rays, and directing the second color of light rays back into the beam splitter/combiner;

a third reflecting polarizing LCD for receiving the third color of light rays from the beam splitter/combiner, shifting the polarization of none, some, or all of the third color of light rays, and directing the third color of light rays back into the beam splitter/combiner;

a lens for receiving and transmitting substantially all of the rays of polarized light whose polarity has been shifted and which have been passed from the beam splitter/combiner to the wide angle reflecting polarizer;

a display surface for receiving rays from the lens; and

an optical device interposed between the lens and the display surface such that the rays travel an image path that reaches the optics twice, passing through an achromatic retarder, before reaching the display surface, wherein the optical device is reflective of some light and transmissive of other light.

29. The projection display apparatus of claim 1, wherein the wide-angle polarizer is adapted to be positioned at approximately 45 degrees relative to the light beam.

30. The projection display apparatus of claim 1, wherein the wide-angle polarizer is adapted to be positioned relative to the light beam at angles substantially away from any Brewster angle of the light beam entering the wide-angle polarizer.

31. The projection display apparatus of claim 1, wherein all the light of the second polarization component of the light beam reflected by the wide-angle polarizer is reflected from a same surface of the wide-angle polarizer.

32. The projection display apparatus of claim 1, wherein all the light of the second polarization component of the light beam reflected by the wide-angle polarizer is reflected into the same optical path.

33. The projection display apparatus of claim 26, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

34. The projection display apparatus of claim 26, wherein the optical device comprises a double brightness enhancement film.

35. The method of claim 27, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

36. The method of claim 27, wherein the optical device comprises a double brightness enhancement film.

37. The projection system of claim 28, wherein the wide angle reflecting polarizer comprises a double brightness enhancement film.

38. The projection system of claim 28, wherein the optical device comprises a double brightness enhancement film.

39. The apparatus of claim 26, further comprising a reflecting device positioned on an opposite side of the wide angle reflecting polarizer with respect to the light source, wherein the reflecting device is configured for reflecting light of the first polarized portion through the wide angle reflecting polarizer to the light source.

40. The method of claim 27, further comprising providing a reflecting device on an opposite side of the wide angle reflecting polarizer with respect to the light source, wherein the reflecting device is configured for reflecting the first portion of the beam through the wide angle reflecting polarizer to the light source.

41. The apparatus of claim 28, further comprising a reflecting device positioned on an opposite side of the wide angle reflecting polarizer with respect to the source of rays of polarized light, wherein the reflecting device is configured for reflecting light polarized in the first direction through the wide angle reflecting polarizer to the light source.

42. The apparatus of claim 1, wherein the image engine further comprises a color wheel/shutter between the light source and an LCD for color sequential operation, wherein the LCD is adapted to generate the polarized image and to control the brightness of the polarized image.

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